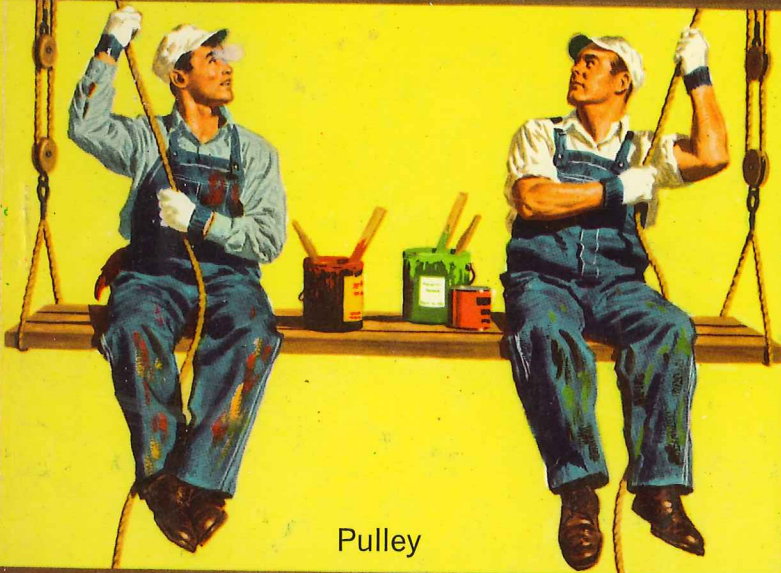


The
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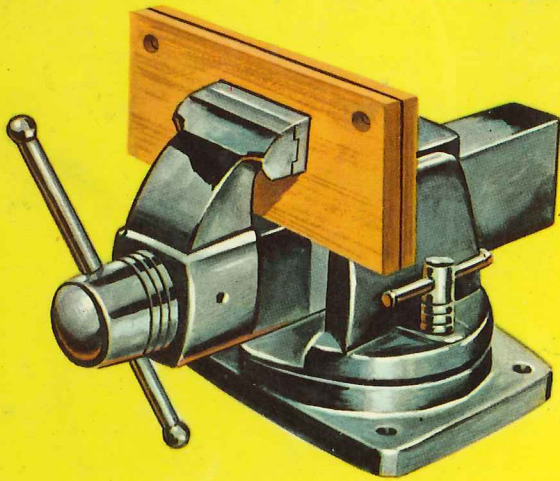
MACHINES



Pulley



Wedge



Screw



Inclined Plane



Lever



Wheel and Axle

How and Why Wonder Books

SIX BASIC PRINCIPLES OF MACHINES



THE HOW AND WHY WONDER BOOK OF MACHINES

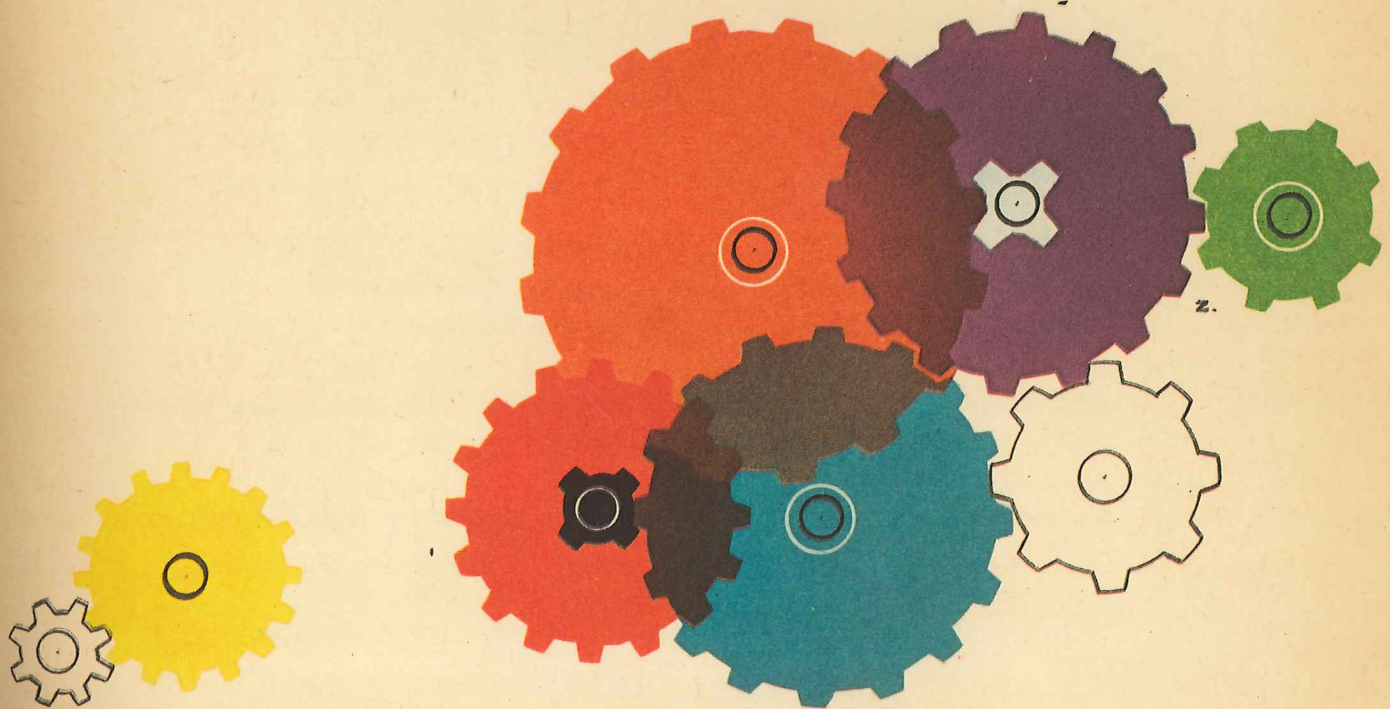
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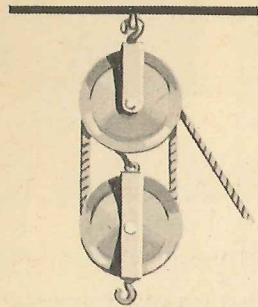
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WONDER BOOKS • NEW YORK



Introduction

The people of very early times may have used machines in primitive ways. As mankind discovered new uses for them, it was able to move from primitive to more civilized ways of living. And the history of civilization almost parallels the ever-widening and ever-wiser use of machines. But, as we learn in this *How and Why Wonder Book*, no matter how complex today's machines appear, they are really combinations of two or more of the six simple ones — the lever, the inclined plane, the wedge, the screw, the wheel and axle, and the pulley.

It is these simple machines which mankind, through the ages, has learned to use in a great variety of ways to help it do its work more easily. This book describes clearly how each type of machine is useful in applying force, in order to make work easier.

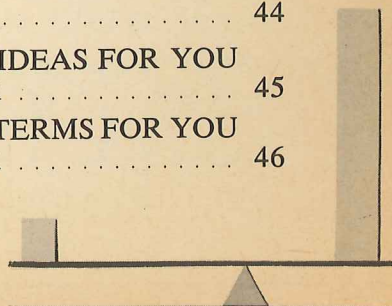
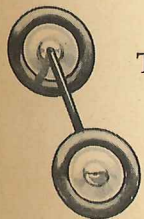
A knowledge of simple machines is of practical value to us as we do various daily chores. It also helps us understand and appreciate how the complex machines do their work.

This book, like several others in the *How and Why Wonder Book* series, includes several interesting experiments. By doing the experiments, children will discover some of the laws of machines for themselves and see why it is that we depend on machines to do so much of the world's work.

Paul E. Blackwood
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The Machine Age

The word "machine" comes from a Greek word, *mechos*, meaning "expedient" or something that makes easy. The Romans used the Latin word *machina*, a word which meant "trick" or "device." The Hebrew word for "machine" is *mechonah*, and as used in the Old Testament and in other Hebrew writings, was variously interpreted as

"foundation," "base," "plan." In an age, long ago, when people had to do all kinds of work by hand, it is not surprising that they searched for "expedients" or "tricks" or "plans" to make their work easier. And they found them. Today, so many jobs are done by machine that the age in which we live is often called the Machine Age.

Breaking Through the Language Barrier

A while ago we saw a clown in the circus struggling to lift a chair which had been nailed to the floor by another clown. We could tell how great an effort our clown was making because he got red in the face and started to perspire. No matter how hard he tried, however, the chair wouldn't budge.

Did this clown do work?

Then another clown came out, picked up a feather from the chair and threw it into the air.

Did the second clown do work?

If your answer to the first question is

What is work? *yes* and to the second one *no*, you are wrong both times.

Work, as spoken of in this book, occurs only when a *push* or a *pull* moves something with *weight* through a *distance*. The push or pull is called **FORCE**, and the weight is called **RESISTANCE**. Remember these two

words well. We will need them throughout the entire book.

Going back to our clowns — the first clown tried to apply **FORCE**

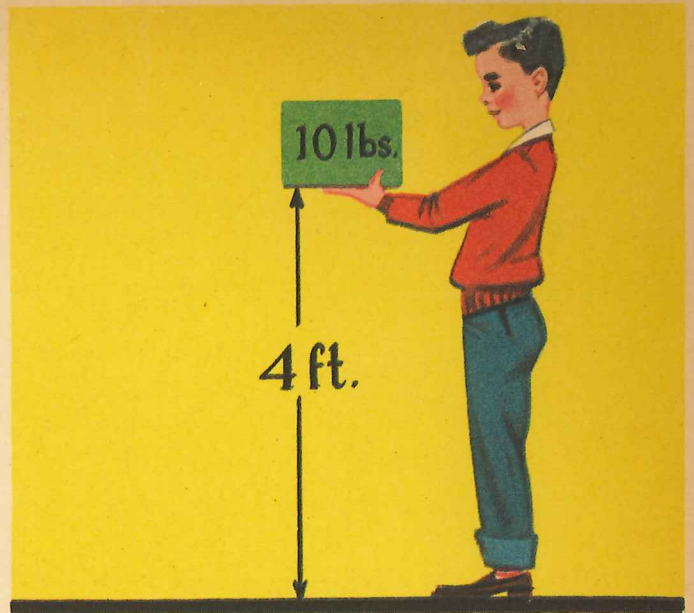


(push or pull) to move the weight (the chair), but he did not move it. The second clown applied FORCE (push) and moved the RESISTANCE (the feather, which, however light, has weight) through a distance, by throwing it into the air.

When you have finished your home-

work, you may say
How is work measured? that you have done
"a lot." In science,

we have to be more precise. We can't say: "The machine worked a lot." But we can say: "There was one *foot-pound* of work done." It sounds strange, but it is just another unit of measure. As the foot is a measure of distance, the foot-pound is a measure of an amount of work. We arrive at this measure by multiplying the force by the distance through which it acts.



Ten pounds raised four feet equals forty foot-pounds.

One foot-pound is the work done by a force of one pound acting through a distance of one foot.

If you lift a weight of ten pounds to a height of four feet, you do $10 \times 4 = 40$ foot-pounds of work, no matter how long it takes.



Which clown is doing work? Answer: The one on the right, because he is applying force and has moved the resistance (the feather).

Power is the rate of doing work. It is calculated by dividing the amount of work done by the time required to do it.

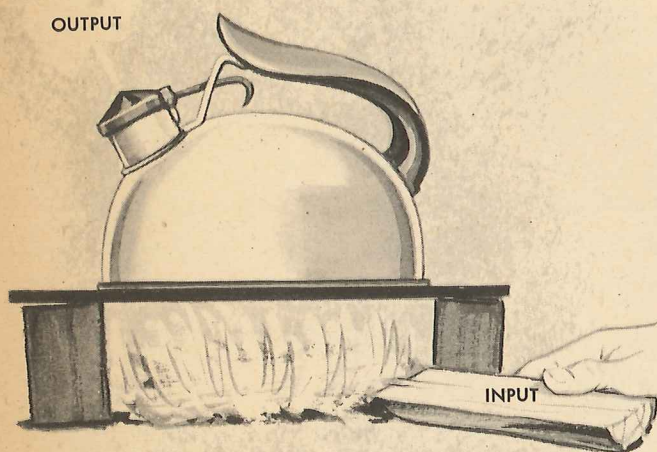
What is power?

The unit usually used to express this is *horsepower*. It is enough for now to know that a machine has one horsepower if its rate of work accomplishes 550 foot-pounds in one second (or 33,000 foot-pounds per minute).

Has someone ever told you that you were not efficient in school? In practically the same way, we speak of efficiency of machines.

What is efficiency?

The efficiency of a machine is the *ratio* (comparative amount) of useful work it does to the total work input.

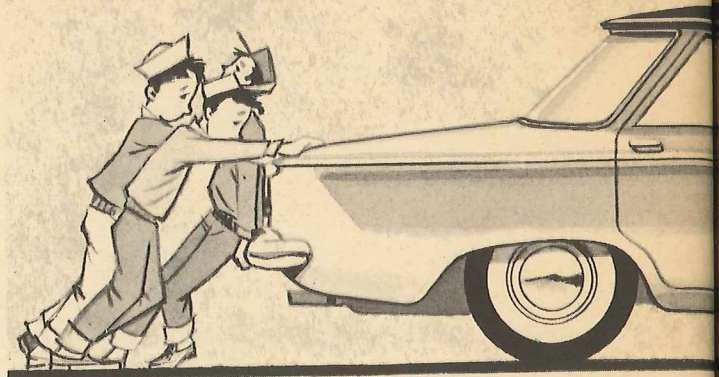


This picture study will help you understand efficiency.

$$\text{Efficiency} = \frac{\text{Work output}}{\text{Work input}}$$

Because of losses due to *friction* — that is, some form of rubbing action — no machine is able to deliver the same amount of work that is put into it.

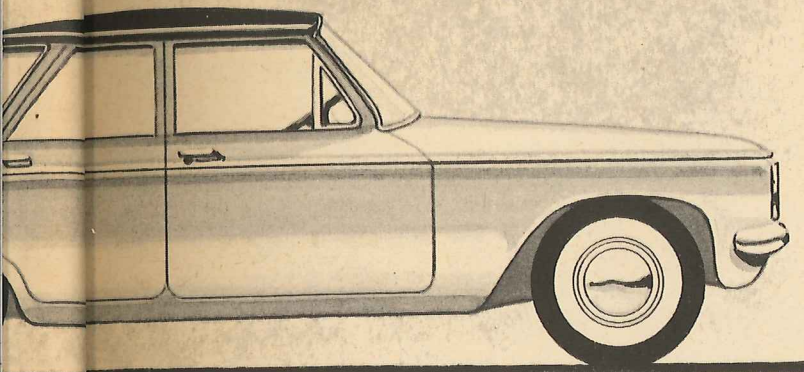
Inertia must be overcome before the car rolls and in order to accomplish work.



You may know from having seen others try to push a stalled automobile that it is more difficult to get it rolling than to push it after it has started to roll. This is due to the tendency of all bodies at rest to remain at rest. The scientists call this tendency *inertia*. You have to overcome the same inertia to stop a rolling automobile, because a body in motion tends to stay in motion. Thus, you have to overcome inertia to accomplish work.

Ask your friends whether it is easier to lift a pound of feathers or a pound of iron. They might answer wrongly that it is easier to lift the feathers. Measured in terms of work, it is the same. In both cases you lift a weight of one pound. But it is harder to lift two pounds than one pound, because you have to work harder to overcome the weight or the attraction of gravity.

Let's go back to pushing the automobile. If the owner has left the brakes set, it may be impossible to move the



car, and if he has left them partly set, it is much more difficult than with no brakes at all. This is due to the rubbing of the brakes against the wheels, or, as the scientists call it, *friction*. Thus, work is hard because matter has inertia and weight, and while working, we have to overcome friction.

Perhaps at some time or other you were told: "Why don't you do something? You have much too much energy." Well, that's exactly what energy is: the ability or capacity to do something, to work.

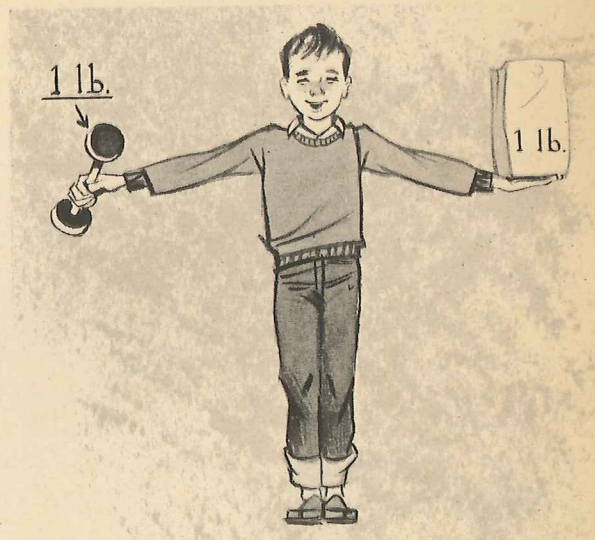
What is energy?



There are many forms of energy — heat, electrical, mechanical and others.

When energy is used in work, force is applied. This means that force is used to push or pull, to cause a body at rest to move, or to stop a moving body, or make it change its direction, or to cause a moving body to lose or gain speed.

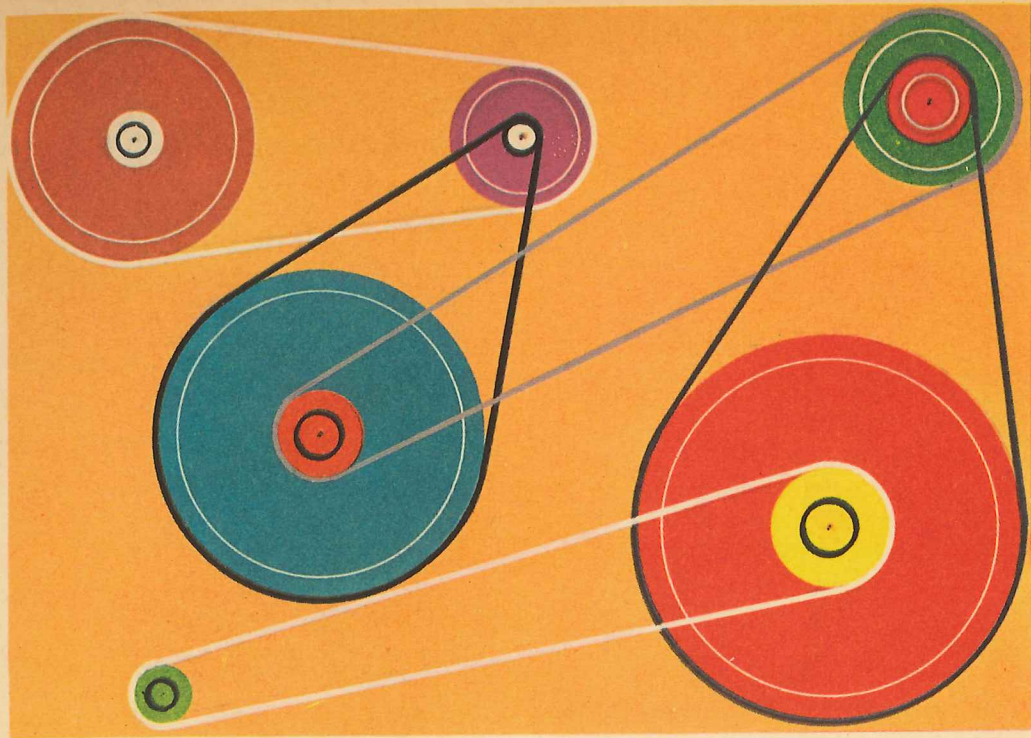
How does energy become active?



Lift either weight. It's the same amount of work.

Overcoming friction helps the boy (right) to skate.





Machines

What, you may ask, has all this to do with the title of this book, the machine? Well, we saw a picture not long ago of a machine with a lot of turning wheels. The machine had a thousand moving parts. When the inventor was asked what this complicated device was supposed to do, he answered, "Nothing at all. It is just a thousand parts in motion."

Was this really a machine? Not in the true sense of the word.

What is a machine? A machine, as we define it here, is a tool or device which, by applying a force (1) makes work easier, or (2) changes the direction of the force, or (3) increases the speed with which work is done. The device with a thousand moving parts, therefore, is not truly a machine, because it is not used to do any work at all.

In other words, we use machines because they make possible a gain in *force*—that is, they enable us to overcome a great resistance with a small effort. When this is the case, we say that the machine gives us a *mechanical advantage* of force. Other machines enable us to move the resistance faster than the applied force is used. Such a machine gives us a *mechanical advantage of speed*.

Later on, as we discuss particular machines, we will figure out exactly how big these advantages are.

Living in a time that is called "The Machine Age," it is difficult to imagine that we did not always have the automobile, the airplane, the locomotive and all the other devices man has in-

Why are machines used?

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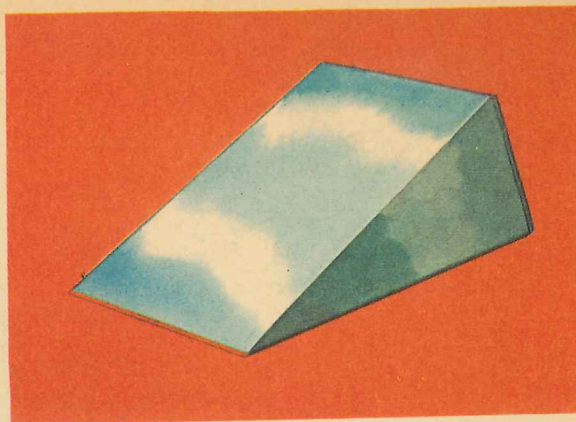
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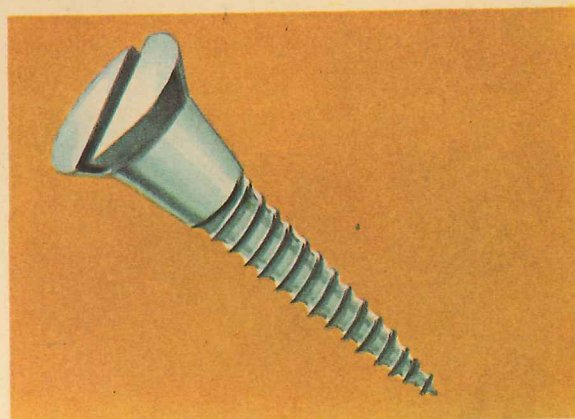
Living in a time that is called "The Machine Age," it is difficult to imagine that we did not always have the automobile, the airplane, the locomotive and all the other devices man has in-

vented to make his work easier. But there was a time, thousands of years ago, when man had no machines at all, and until not too long ago he relied on the strength of his muscles or the muscles of animals for the energy necessary to operate the simple machines he had devised and constructed.

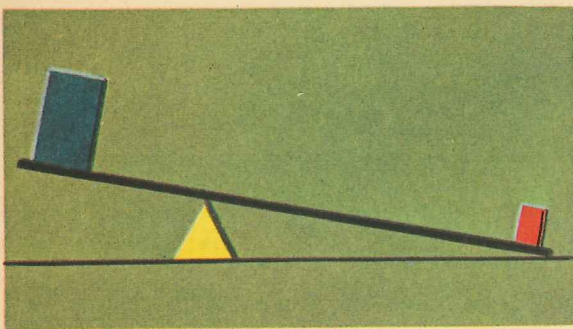
Even in very early times, man tried to use tools to make his work easier. **What are the six basic machines?** These tools or machines were primitive, and were constructed because of need. In fact, these primitive machines are still used today in one form or another, and even our most complicated modern machines are combinations of the six basic ones already in use early in man's existence. The six basic machines are:



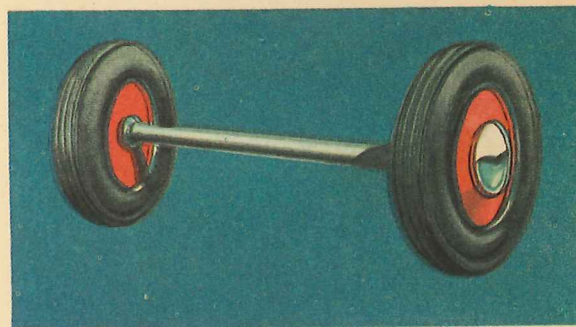
The wedge



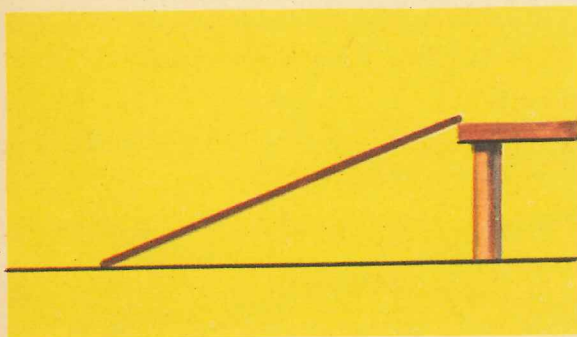
The screw



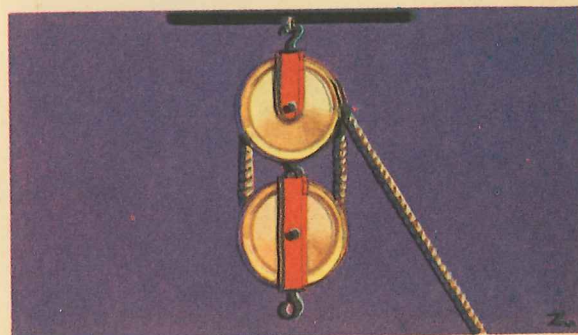
The lever



The wheel and axle



The slope, or inclined plane

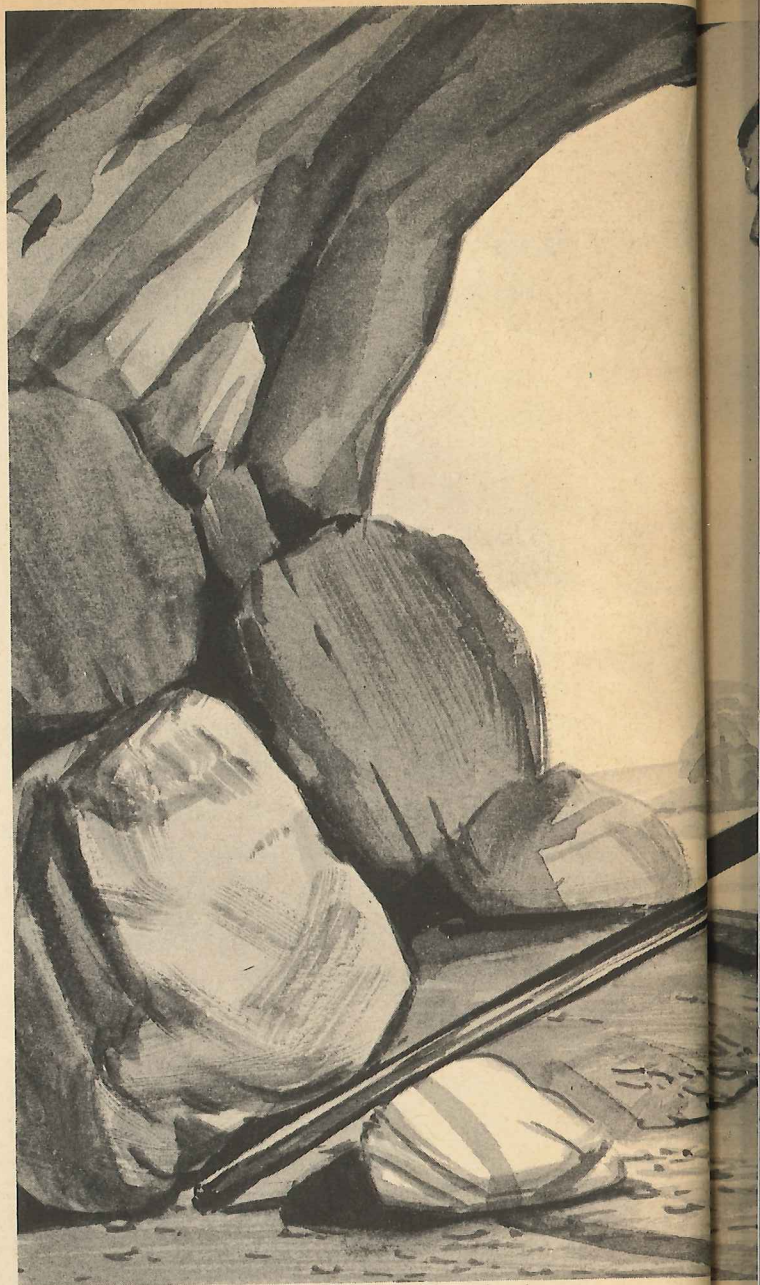


The pulley

The Lever

Can you imagine primitive man trying to protect the entrance to his cave by putting a large boulder in front of it? He is a strong man, but not strong enough to lift the rock — not even strong enough to roll it. Nobody knows who first had the idea — nobody is credited with the invention of this primitive machine, but one day somebody tried to move the stone by resting a long, strong branch on a smaller stone, pushing the end of the branch under the boulder, and pressing down on the branch.

How does the lever make work easier?



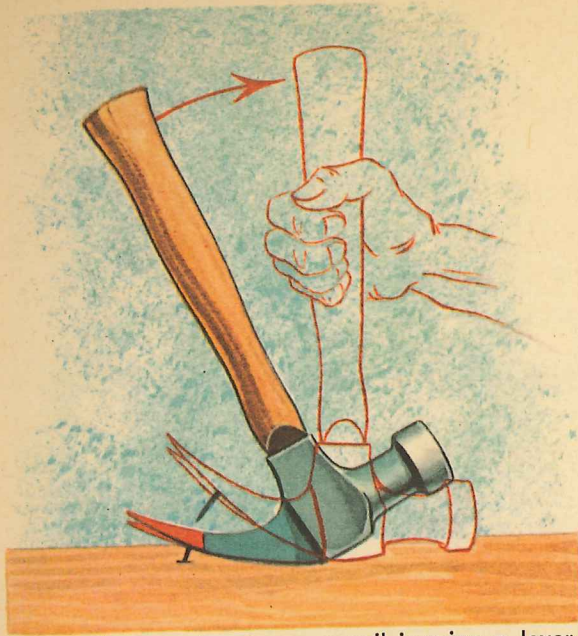


Can you imagine the pride that man must have felt when he succeeded, without even too much effort, in moving the rock? He did not know that he had invented the machine which we call the "simple lever." By experience, primitive man found that the longer the lever, the more weight could be lifted with less effort. He learned this in the same way you found out where you have to sit on a seesaw to stay in balance, or that the farther you move from the point where a seesaw hinges on its rest,

the easier it is to lift your heavier playmate on the other end. The seesaw, too, is a lever.

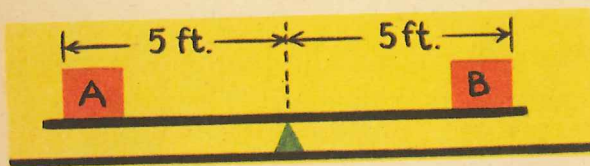
The smaller stone in the first picture and the middle point of the seesaw have the same function: to provide a rest for the lever. This rest is called the *fulcrum*. The side where you apply the force is called the *effort*. The opposing side is called the *resistance*.

The lever need not always be straight, like the cave man's branch or the board of the seesaw. Sometimes the lever is

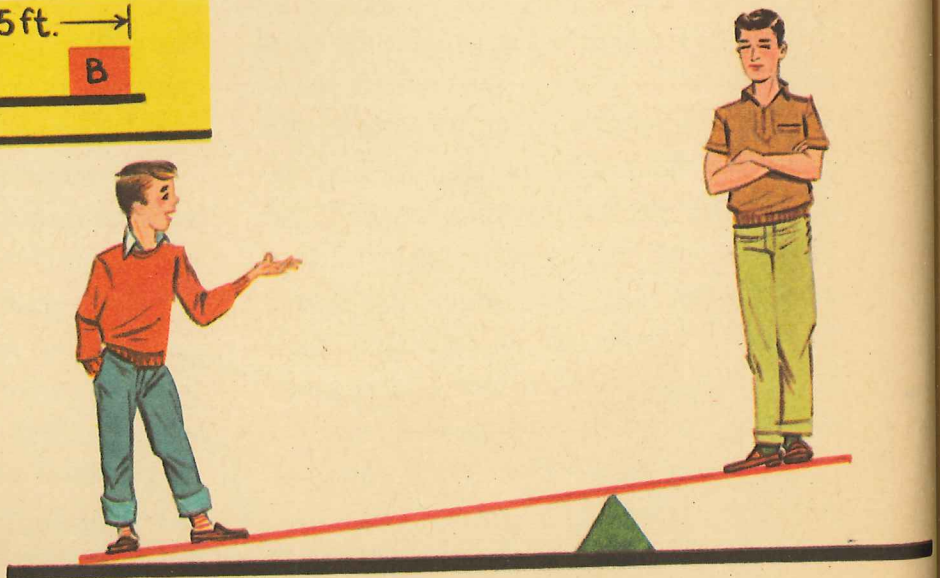


Using a hammer to remove a nail is using a lever.

curved. When you pull a nail with a claw hammer, you are using a curved lever. The fulcrum is at the head of the hammer. You push down on the handle and the nail comes out. So, you see, we started with a primitive machine and find that it is still in use, in practically its original form, on the playground, in the house, and as part of more complicated machines.

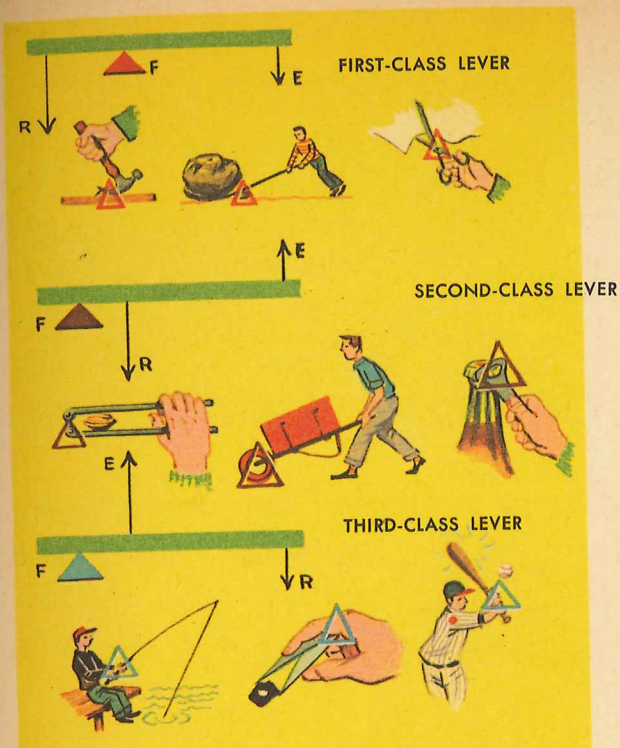


The boy on the left will have to move closer to the fulcrum to balance the seesaw.



Early man used the lever, as we have seen, but it was not until thousands of years later —about 240 B.C.—that the Greek scientist, Archimedes, discovered what we call the Law of the Lever: Two loads, A and B, balance when the scale-pan weight of A multiplied by its distance from the fulcrum is the same as the scale-pan weight of B multiplied by *its* distance from the fulcrum. As the force exerted on a machine is called effort, we call the distance from the effort to the fulcrum the *effort arm*, and the distance from the resistance to the fulcrum the *resistance arm*.

There are three classes of levers, depending on the relative position of the effort (E), fulcrum (F), and resistance (R). The first-class lever has F between E and R. Examples of the first-class lever are the crowbar, the seesaw and the pump handle. Now that you know Archimedes' **What are the three classes of levers?**



First-class lever: The fulcrum (F) is between the effort (E) and the resistance (R).

Second-class lever: The resistance (R) is between the fulcrum (F) and the effort (E).

Third-class lever: The effort (E) is between the fulcrum (F) and the resistance (R).

Law of the Lever, you can surprise your friends, after you know their weight, by figuring out exactly where you have to sit on the seesaw to balance your heavier or lighter companions — or, better

still, where you have to put the lever on the fulcrum to be able to lift them up.

Sometimes two levers are used together

Why are scissors a double lever?

to form a double lever. A pair of scissors is such a double

lever. The screw joining the two blades is the fulcrum. Try to cut a piece of cardboard with a regular pair of scissors and demonstrate for yourself the Law of the Lever. You will find that if you try to cut with the points of the scissors, you will not succeed. But when you use the scissors so that you cut close to the fulcrum, you will succeed because you have more force.

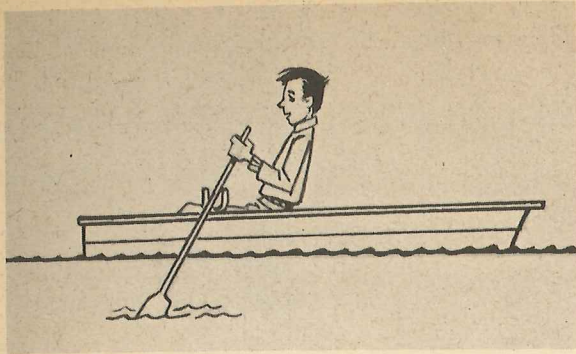
We have seen that by using the long end

What is a second-class lever?

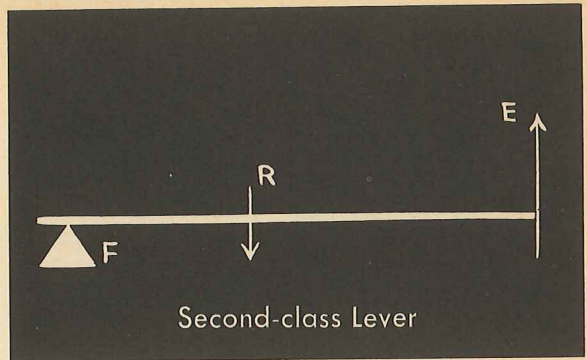
of a lever we get more power and are able to do a hard job using little force. Look at the

oars of a rowboat. The ends of the oars are the effort, the oarlocks are the resistance, and the pivotal points of the oars (the ends in the water) are the fulcrum.





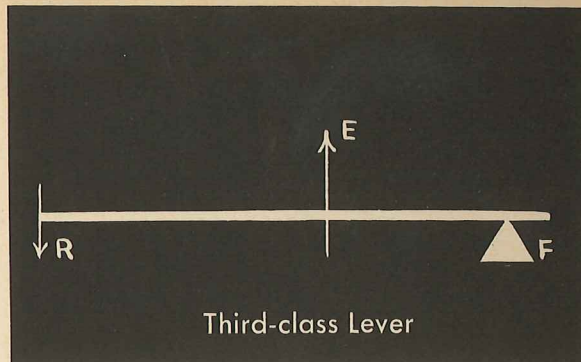
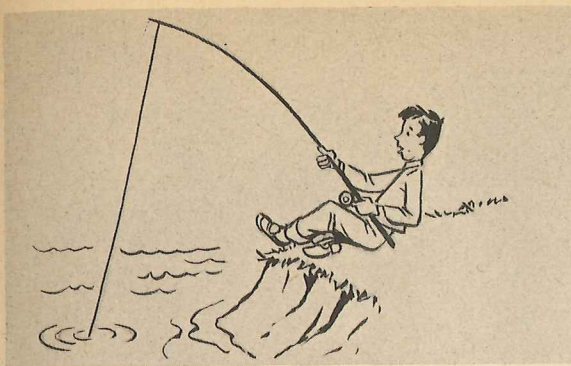
Watch closely when you row: The end of the oar in your hand — the effort end — moves farther than the resistance part in the oarlock. There is more force at the resistance. Just as in the case of the seesaw, we move the effort through a greater distance to get, in return, a greater force. So, in both cases, we trade distance or speed for more force. Other common examples of the second-class lever are the nutcracker and the wheelbarrow.



If you are amazed that you use a lever by riding a seesaw and another kind of lever rowing a boat, think how much more surprising it is that you use the third kind of lever when you fish with a rod. Stop for a moment and try to figure it out for yourself. Does it help if we tell you that in the third-class lever, the effort is between the fulcrum and the resistance? E is between F and R. The end of the

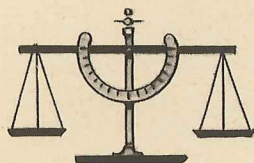
What is a third-class lever?





fishing pole nearest you is the fulcrum. The effort is the part you are holding and the resistance is at the far end of the pole. Here, for the first time, we exert more force at the effort than there is at the resistance. When you pull a fish out of the water, you will notice

that the distance the resistance moves is greater than the distance the effort moves. Sugar tongs, our arms and legs, a broom and a baseball bat are other examples of this type of lever. In the third-class lever, we trade force for more distance and speed.



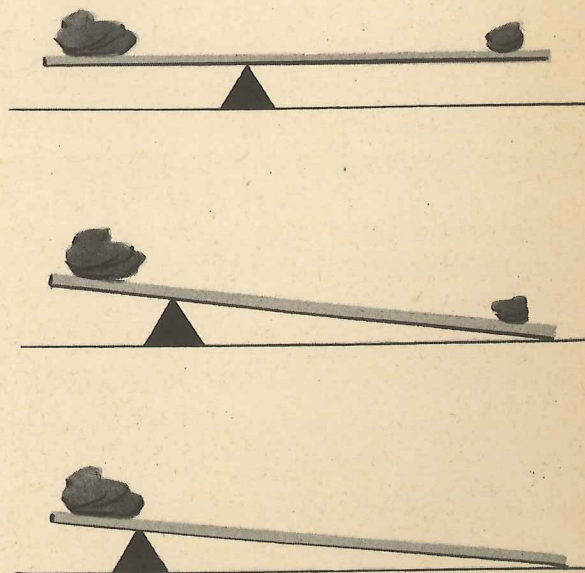
How You Can Experiment With a Lever

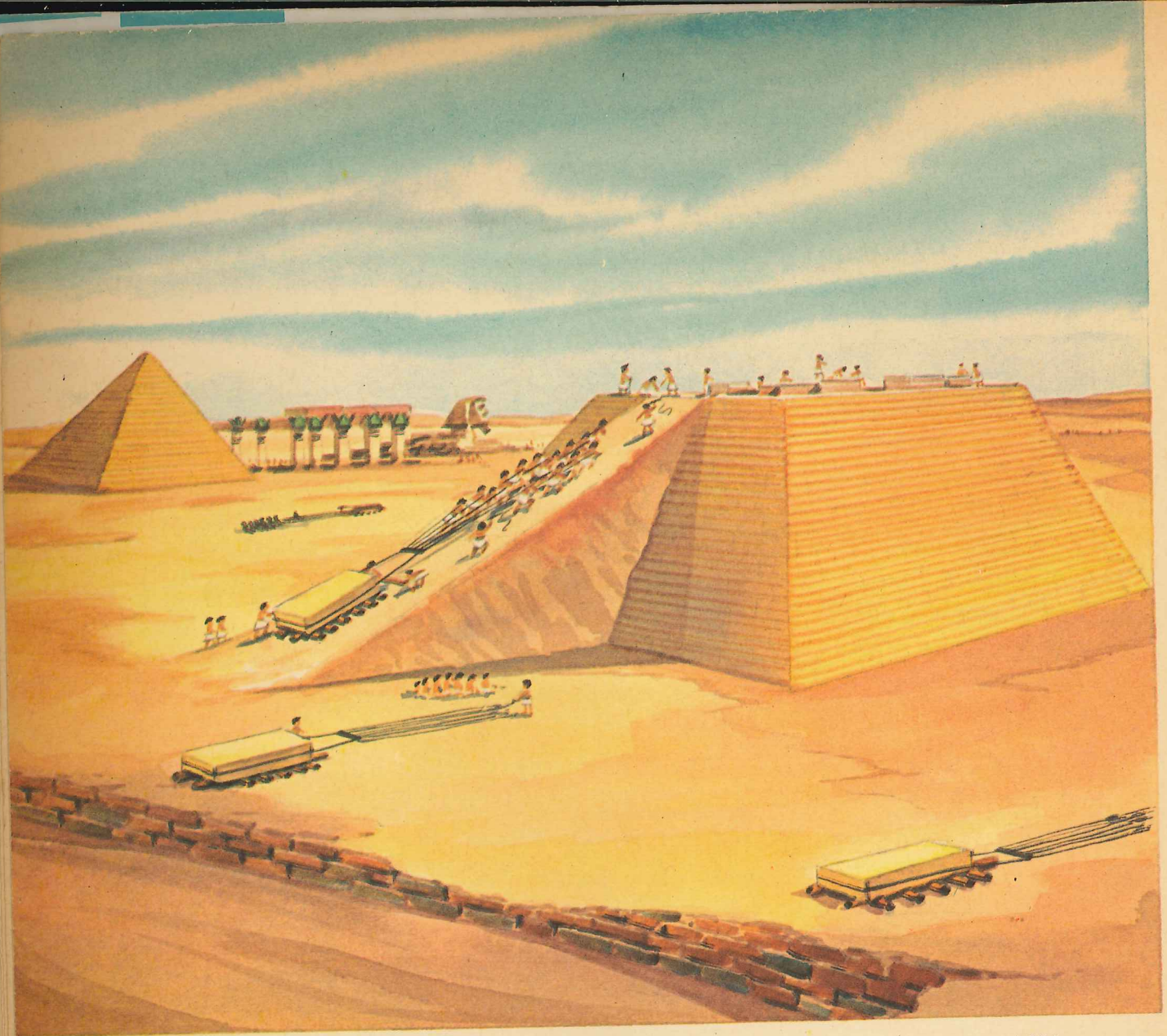
It is fun to check the Law of the Lever with a simple experiment. Build yourself a first-class lever with a ruler, a triangular piece of wood and two stones — a large one and a small one. Now try to figure out the following problems:

(1) where to put the ruler on the fulcrum to balance the two uneven weights.

(2) where to put the ruler to lift the heavier weight.

(3) whether it is possible to shift the ruler along the fulcrum until the weight of the ruler by itself lifts the weight.



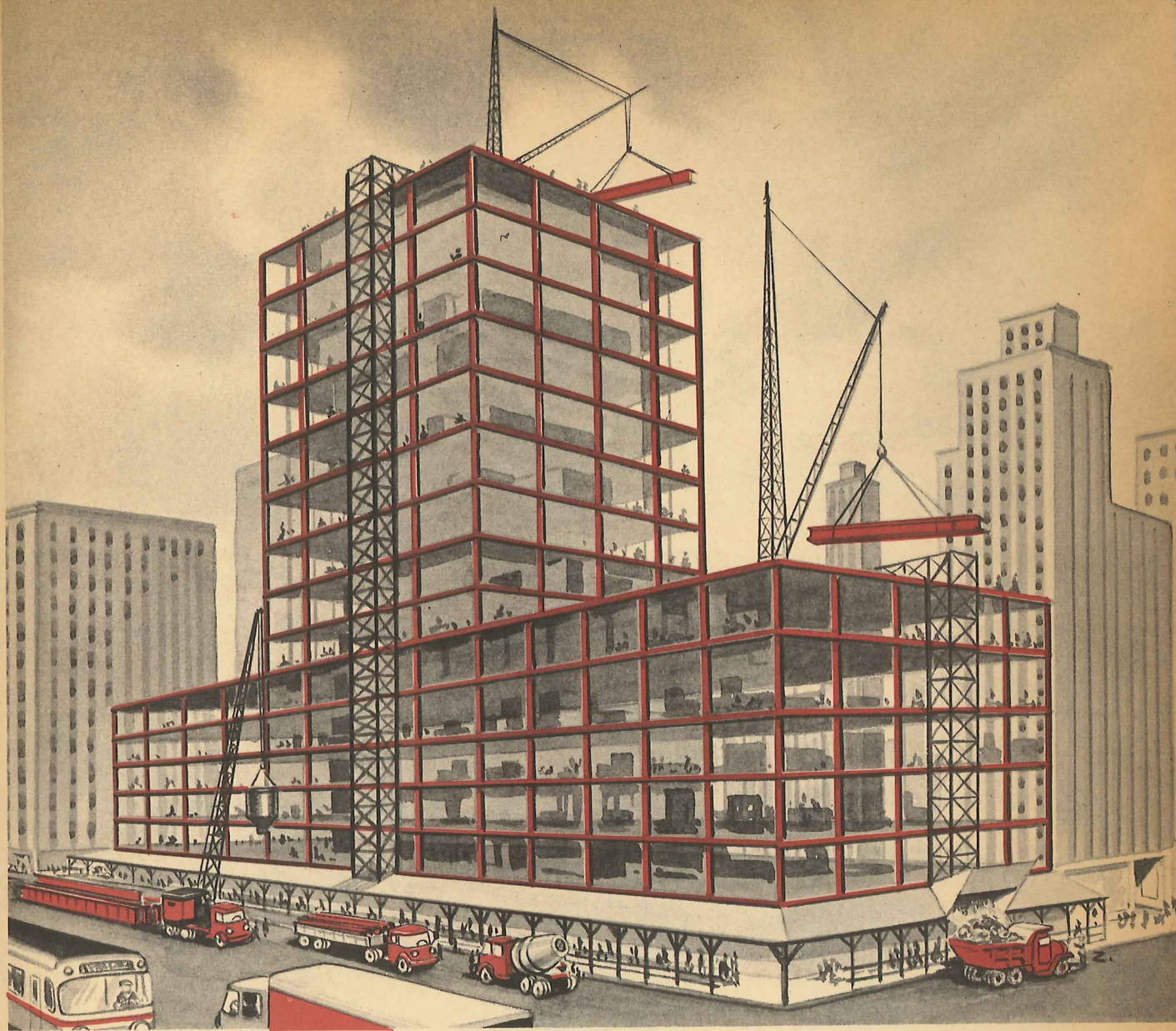


The ancient Egyptians used the principle of the inclined plane when they built pyramids about 4,000 years ago.

The Inclined Plane

Have you ever watched the construction of a large building? **How does the inclined plane help in building?** Have you wondered how so few men do the big job in such a relatively short time? If so, look around the next time and notice the many machines that help the men do their work — the steam shovel, the power drills, the elevators that carry the building materials to the floors high

above the ground, as well as other equipment. Now think of the huge buildings of the ancient Romans, the Greeks, and — even earlier — the Egyptians. You surely have seen pictures of the pyramids, the tombs of the pharaohs and their queens. Just imagine these massive structures being built without the help of elevators and steam shovels — with only human effort as the source of power.



Fewer men, less time and more machines are used to build skyscrapers than it took to build the pyramids.

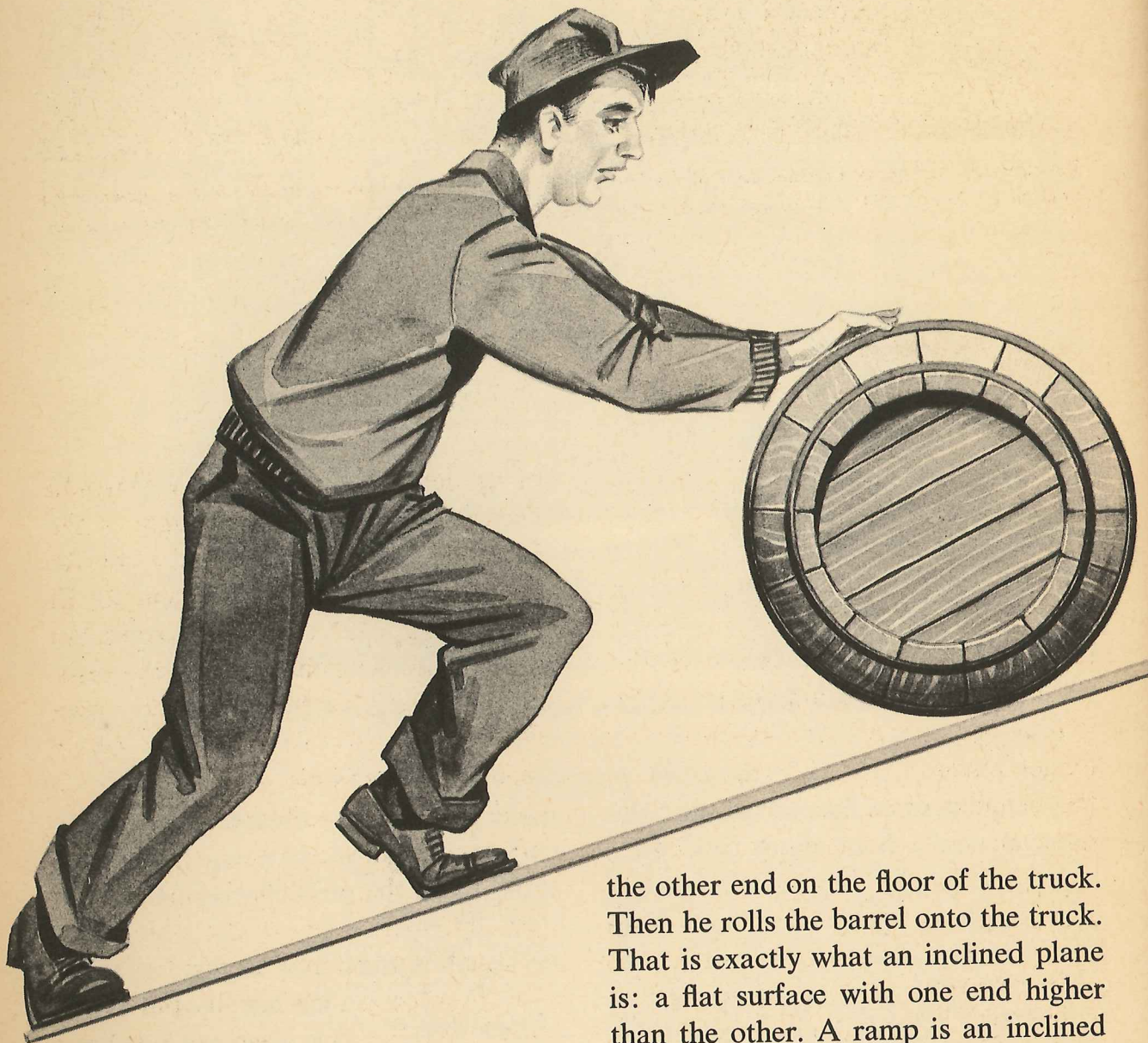
A scientist once figured out that the Great Pyramid, built about 2885 B.C., contains 2,300,000 blocks of limestone, each weighing about two and a half tons. Is it surprising to learn that it took about 100,000 men twenty years to build? How did they manage to get the heavy blocks up to the necessary height? The lever was not much help in solving this problem. They did not have elevators, but they did have the slope, or inclined plane, another of the six simple machines. The inclined plane did not

make it possible for them to do the work as fast as our modern machines, but it did make the project possible.

Have you noticed that the long way up a hill is the easier way?

How does the inclined plane make work easier?

It is also easier, as you will have noticed, to go up many shallow stairs leading to the same height. The ancient Egyptians had noticed these things, too, and they built a slope and pulled the stones into place



instead of trying to carry them up. They did, on a large scale, the same thing a trucker does today when a barrel is too heavy for him to lift. He takes a flat surface — a heavy board, for example — places one end on the ground and

the other end on the floor of the truck. Then he rolls the barrel onto the truck. That is exactly what an inclined plane is: a flat surface with one end higher than the other. A ramp is an inclined plane, and so is a mountain road. The inclined plane is used to help raise a body that is too heavy to be lifted straight up. Just as with the lever, this is accomplished by exerting a smaller force through a greater distance. The



The stairway leading to the front door of the house on the left is longer than the straight ladder shown in the back of the house. Still, it takes less effort to climb the stairway. The winding road (right) is an inclined plane.

amount of work is the same, whether the inclined plane is long or short, but it is easier to move the load over the longer distance. The less the angle of the inclined plane, the longer the distance and the less the effort needed.

Just as in the case of the lever, resis-

How do you figure out the law of the inclined plane?

Suppose you want to lift fifty pounds five feet above the ground and you have a board ten feet long to make your inclined plane. Since the height above the ground is one-half

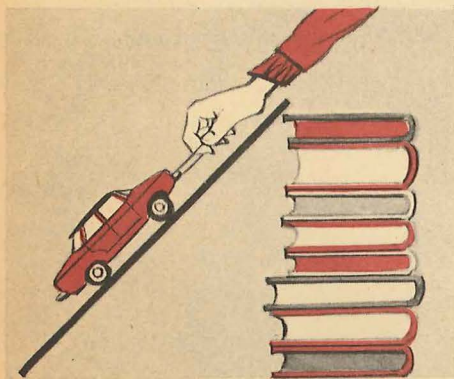
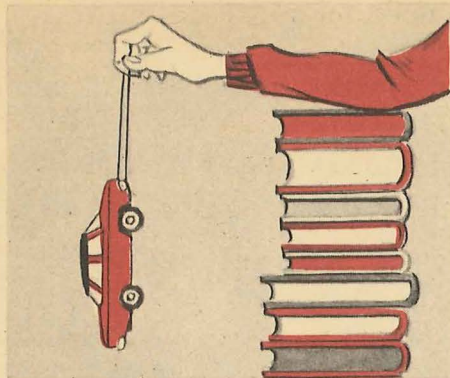
tance times distance equals effort times distance. Now let's do some figuring:

Suppose you want to

of the length of the board, you would need only one-half of the weight of the force to pull the weight. In other words, twenty-five pounds of force should lift fifty pounds. Our arithmetic is right, but what about friction, which is the resistance caused when one object moves against another? We are safe in saying that in the example above, it takes a little more than twenty-five pounds to lift fifty pounds, and the smoother the board and the object to be moved, the less the resistance. If the object has wheels, the resistance is even less. That is why moving men usually put heavy furniture on a dolly before putting it on the ramp or other inclined plane.

To find the advantage in using the inclined plane, divide the length of the plane by the height. In our example, the *mechanical advantage* would be ten divided by five, or two.

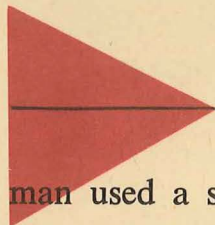
How You Can Experiment With an Inclined Plane



Take a pile of books — about one foot high — and put them on a table. Now attach a rubber band to the front of a toy car, rest your arm on the stack of books, and let the car hang by the rubber band. See how the weight of the car stretches the rubber band to a point where it might even break.

Now take a board, lean it against the books, and pull the car slowly up the inclined plane. You will see that the rubber band will not stretch as far as before, nor will it break.

If you have a spring balance, you can make the experiment even more scientific. Replace the rubber band with the spring balance and you will be able to check on the exact force needed to pull the weight of the car.

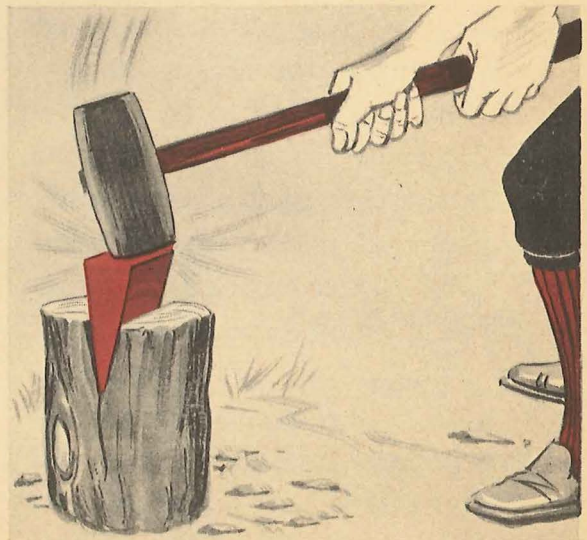


The Wedge



When early man used a stone instrument to split the skin of an animal, we can be pretty sure that this stone was another of the six simple machines — the wedge. He didn't know at the time that he was using a "basic machine." He knew only that he was using something that enabled him to accomplish a task with less effort. The ancient Egyptians knew much more about the mechanical advantage of the wedge than primitive man. They

How is the wedge related to the inclined plane?



Splitting wood is made easier by using a wedge.

put two inclined planes together — back to back — and made a wedge. You could call that a movable inclined plane combination.

The wedge is used to overcome large resistance. You have probably seen the picture called "The Railsplitter," showing Abraham Lincoln using a wedge to split rails. The wedge is hammered into the log and splits it. Actually, all of our piercing tools, such as the ax, the needle, the knife, the carpenter's plane, and many others, are forms of the wedge.

How is the wedge used?

It is easy to understand the advantage of the wedge if you think what would happen if the knife or the needle were dull or the carpenter's plane had no blade. However, it is rather involved to figure out the exact mechanical advantage of the wedge as we did with the lever and the inclined plane. This is so because it is difficult to calculate the friction, and because the force applied to this machine is not steady as in the others. The force is intermittent; that is, it is applied in a series of uneven blows or stabs.

What is the advantage of using the wedge?

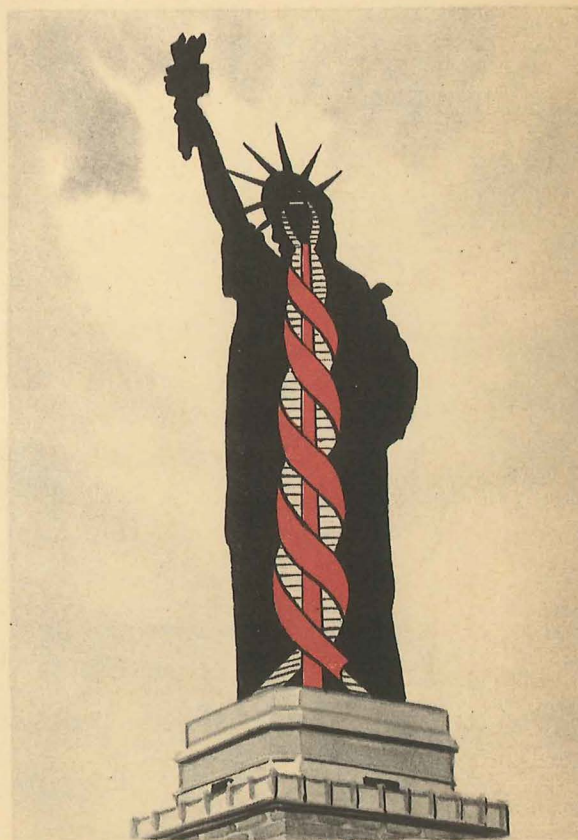
The Screw

You have been introduced to the inclined plane and to its cousin, the wedge. Now let's make the acquaintance of its other cousin, the screw. One of the best, and certainly one of the largest, examples of this simple machine is the staircase inside the Statue of Liberty in New York City. It is a steep spiral stairway which has 168 steps leading up to a balcony in the forehead of the statue. If you look at the illustration, you will see why we call it a giant screw, but can you see why the screw is related to the inclined plane?

How is the screw related to the inclined plane?

A screw is an inclined plane wrapped around a round object such as a pole or a cylinder.

Screws are generally used to hold



The staircase inside the statue resembles a screw.

The Wheel

Look around you, at home, in the street,

Why was the invention of the wheel important?

transportation at all, none of our complex machines and not even most of the simple ones. Even if machines are not all based on the wheel, most of them use it in one or another combination.

Just as we do not know who invented

What do we know about the development of the wheel?

and where it was used for the first time. We can assume that early man already had noticed that a round object moved more easily than one that was not round. We may assume that early man used logs to roll loads for short distances, but these were not really wheels.

We know that as far back as 4000 B.C., the Sumerians made use of the wheel. It was a heavy disk connected to an axle. It did not look at all like our wheel of today, but it was round and functioned as our wheel does.

The next improvement came when someone constructed a wheel with cross-bars in an attempt to make it stronger.

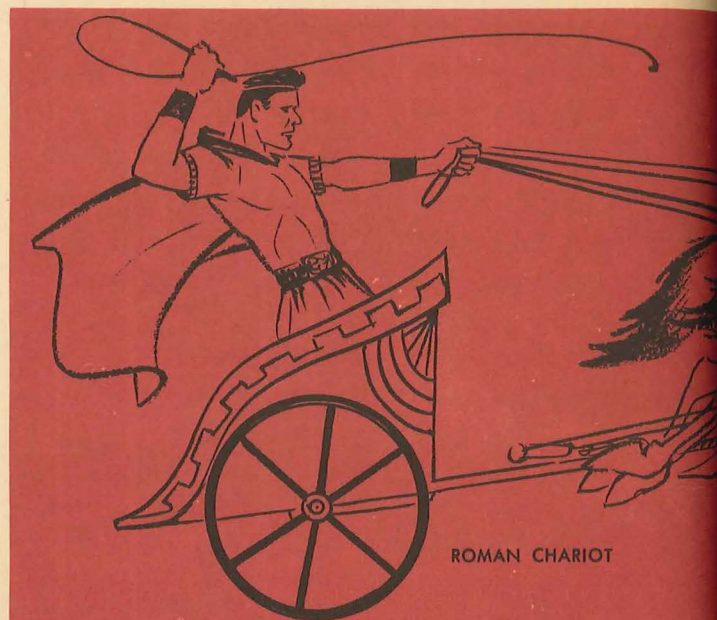
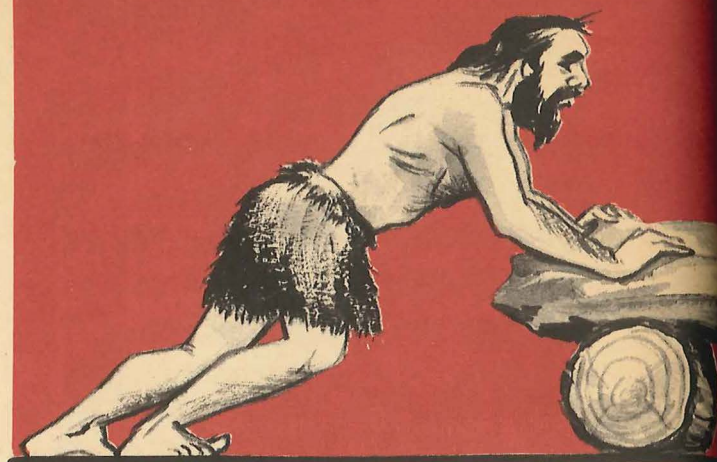
The Egyptians made bronze wheels with spokes, which were quite strong and much lighter than the earlier wheels. They looked very much like a modern wheel. No doubt it already was

wherever you are or go, and just think what it would be like without the wheel.

There would be no

the other simple machines, we do not know who invented the wheel. We do not even know when

Primitive man made use of logs to move heavy objects.



ROMAN CHARIOT



SUMERIAN WHEEL



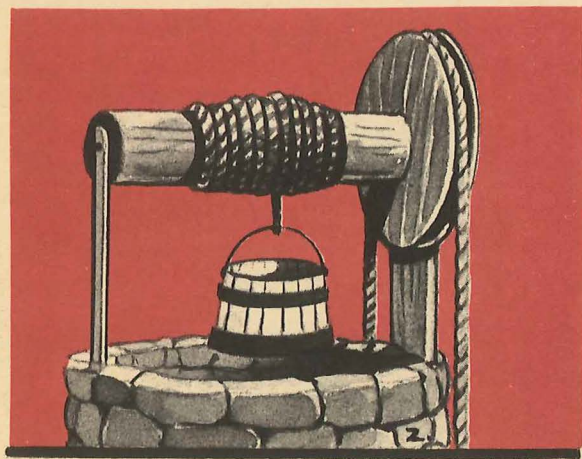
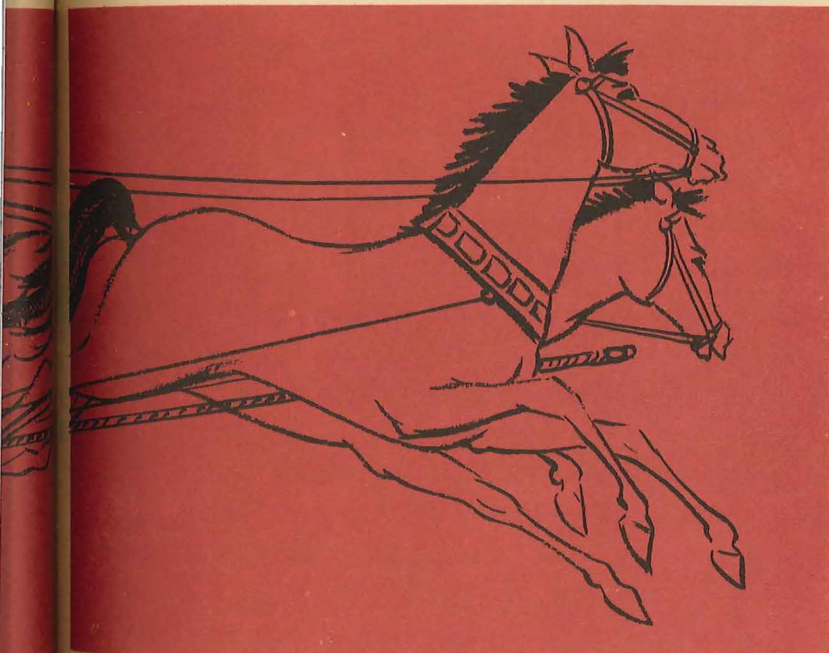
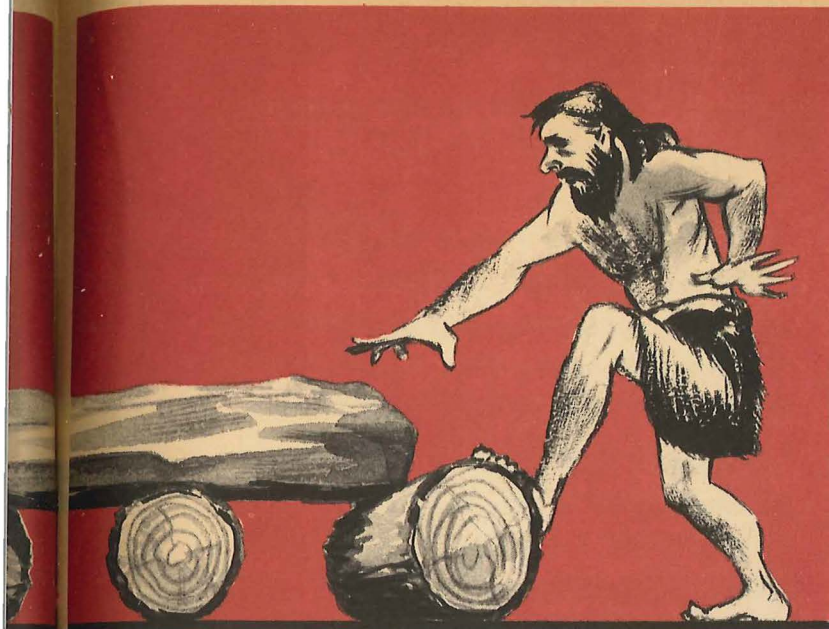
GALLIC WHEEL



ROMAN WHEEL



DA VINCI WHEEL



The windlass is a combination of a wheel and an axle.

a wheel rolling on its way to better and finer wheels to make work easier for all.

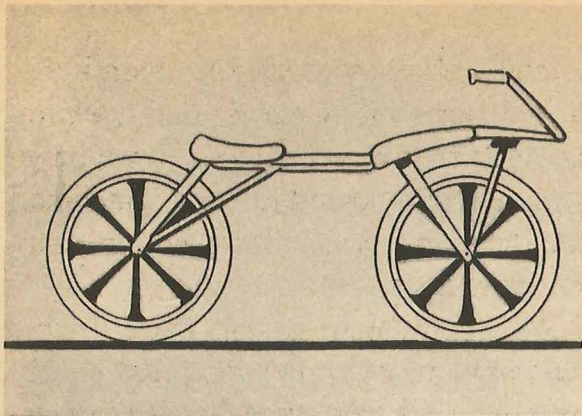
The Italian painter and inventor, Leonardo Da Vinci, who lived about five hundred years ago, improved the wheel further by making it lighter and stronger than it was. You don't have to look too closely to see the resemblance to our bicycle wheel of today.

The wheel in itself is not a machine, but it becomes one when you combine it with an axle or another wheel. Actually, the

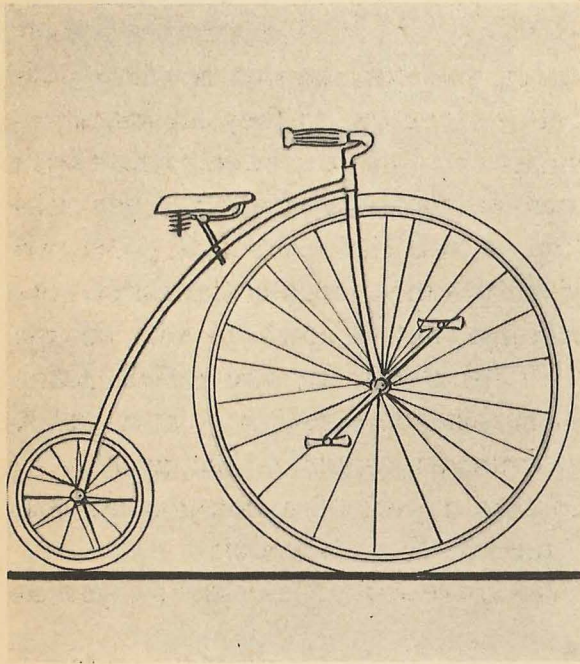
What makes the wheel a basic machine?

axle is nothing but a second wheel, fastened rigidly to the first so that the wheel and axle turn together. Let's examine now the principles of the wheel and axle on a machine used by farmers years ago to raise water from the well — the windlass. The picture shows the larger wheel, attached to the axle, being four times the size of the axle; that is, the diameter of the wheel is four times the diameter of the axle. One complete turn of the large wheel will turn the axle, or smaller wheel, four times. The rope fastened to the axle also will be wound four times around the axle. If you were operating this machine, you would be able to do the work of four persons who did not have it.

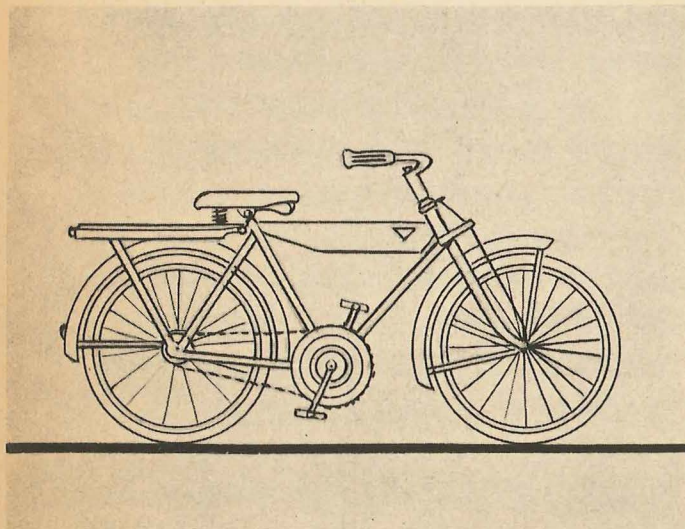
You can also apply the laws of the lever to the wheel and axle. Going back to the windlass, let's say that if the big wheel makes one turn, it moves through a circle of four feet, and the bucket weighing forty pounds moves one foot up the well. Do you remember the law of the lever? The effort multiplied by the length of the effort arm equals the



The very first bicycles constructed had no pedals.



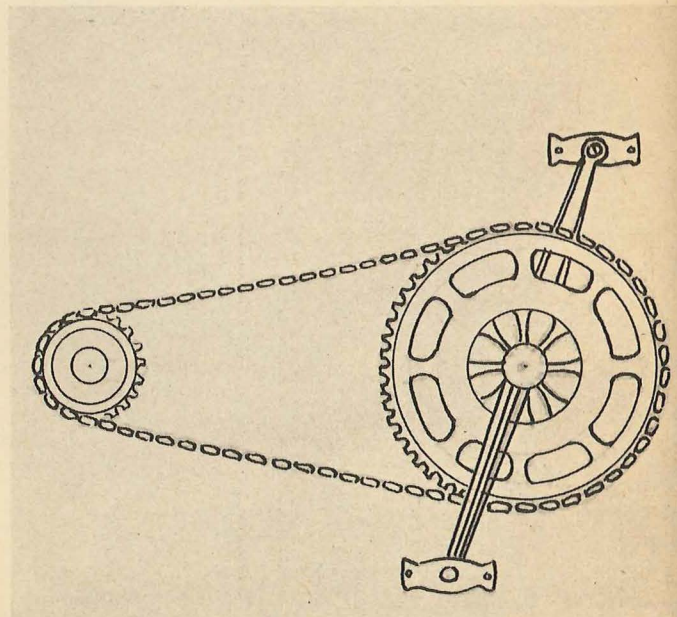
Later, pedals were connected to the large front wheel.



The pedals on today's bicycles turn the back wheel. The chain around this wheel turns the smaller, notched wheel.

resistance multiplied by the length of the resistance arm. In our example, 40 (the resistance) $\times 1$ (the length of the resistance arm) equals 4 (the length of the effort arm) $\times 10$. In other words, an effort of ten pounds raises a bucket of water weighing forty pounds — a mechanical advantage of four.

The idea that was behind the wheel and axle in the example of the windlass was also the idea behind the early bicycle. You probably remember from pictures that the front wheel with the pedals was very large, while the rear one was very small. When the rider turned the large wheel once with the foot pedal, the rear wheel turned many times. For example, suppose the small wheel were only one-quarter the size of the big wheel: When the rider turned the big wheel once with the pedal, the small wheel would turn four times. Such a bicycle would go four times faster than the same bicycle with two of the smaller wheels.



You have seen, in the examples of the windlass and the early bicycle, how the wheel and axle work. Now let's examine the modern bicycle. We go easier and faster on the modern bicycle than people went on the early one, with its big front wheel and short rear wheel. Yet the front and rear wheels on the modern bicycle are the same size. It would seem as though what we explained before was wrong, but let's look closer.

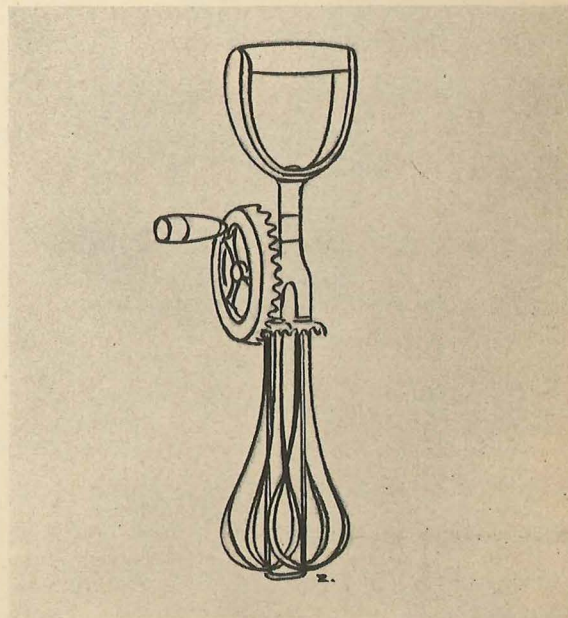
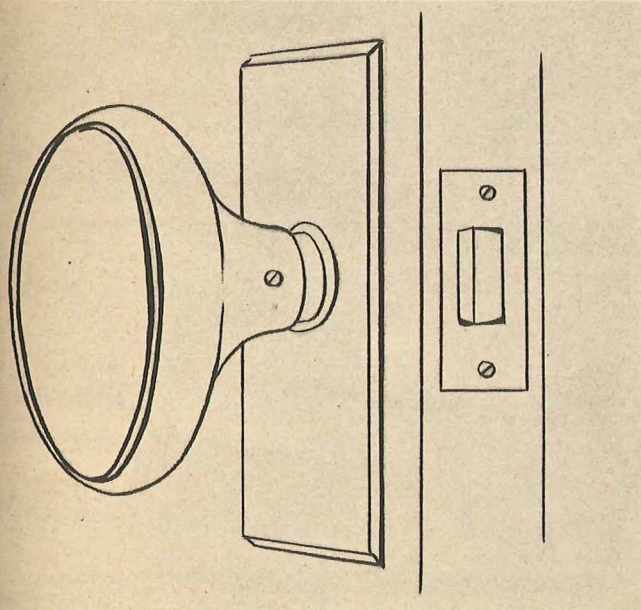
The inventor has attached a notched wheel and cranklike contraption with pedals to turn the wheel, to the front of the bicycle, just comfortably between the front and rear wheels. He also has provided a chain to fit exactly over the notches and a smaller notched wheel to fit the chain on the axle of the rear wheel. This small notched wheel turns with the rear wheel. When the large notched wheel with the chain and pedals is turned once, the rear small

notched wheel to which the chain is attached turns many times, thus turning the large rear wheel with it. So we have a more complicated-looking machine, but the same basic principles obeying the same laws.

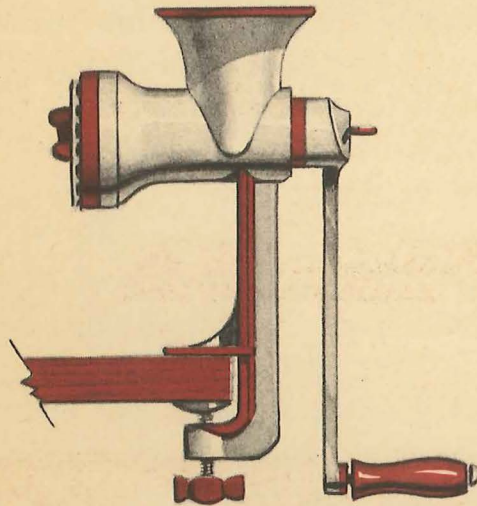
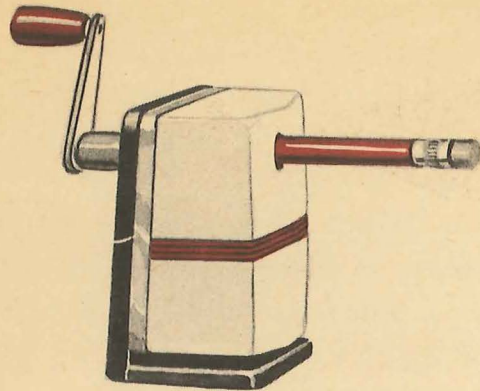
We do not have to go back to the windlass or the more complicated bicycle to study our problems. The doorknob is also a machine with a big wheel that turns a small wheel, and so is the eggbeater. If you examine the eggbeater, you will see that a wheel with teeth — or cogs, as they are called — engages and moves another wheel with cogs. In the modern bicycle this was done with a chain connecting the two wheels. In the eggbeater there is no connecting chain. Cogwheels that engage each other directly are called gears. Does this ring a bell in your mind? A machine as simple as the gear is an important part of a complicated machine like the automobile.

To make it a little easier for you to

How can wheels turn other wheels?



The doorknob and the eggbeater show two practical uses of the combination wheel and axle principle.



The meat-grinder above needs a longer effort arm.

recognize all the little and large machines that are basically wheel and axle, let us say that you can replace the large wheel by a crank, which acts like a wheel. Does this set the wheels turning? The pencil sharpener, the meat grinder, the crank that started the early automobiles . . . yes, all wheel and axle.

Let's see what we have learned — or

Why is a meat grinder handle longer than that of a pencil sharpener?

better, let's find out what we remember. Yes, indeed, the laws of the lever again!

As it is harder to grind the meat than to sharpen the soft wood of a pencil, we need the longer handle or effort arm to achieve our result with as little effort as possible.

Before we explain the one remaining simple basic machine — the pulley — let's first experiment a little with the wheel and axle.

How You Can Experiment With a Wheel

Take a board, drive a nail in the near end, and attach to it a rubber band or — if you have one — a spring balance. Place a weight on the board. Now pull gently on the rubber band or the balance. If you have a balance, you can figure out the force of how many pounds you need to pull the board across the table. If you use a rubber band, you must simply try to

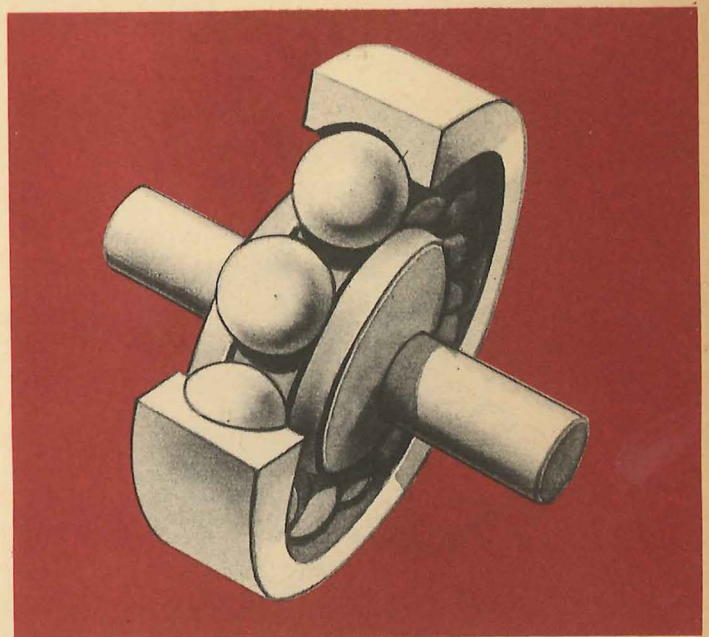
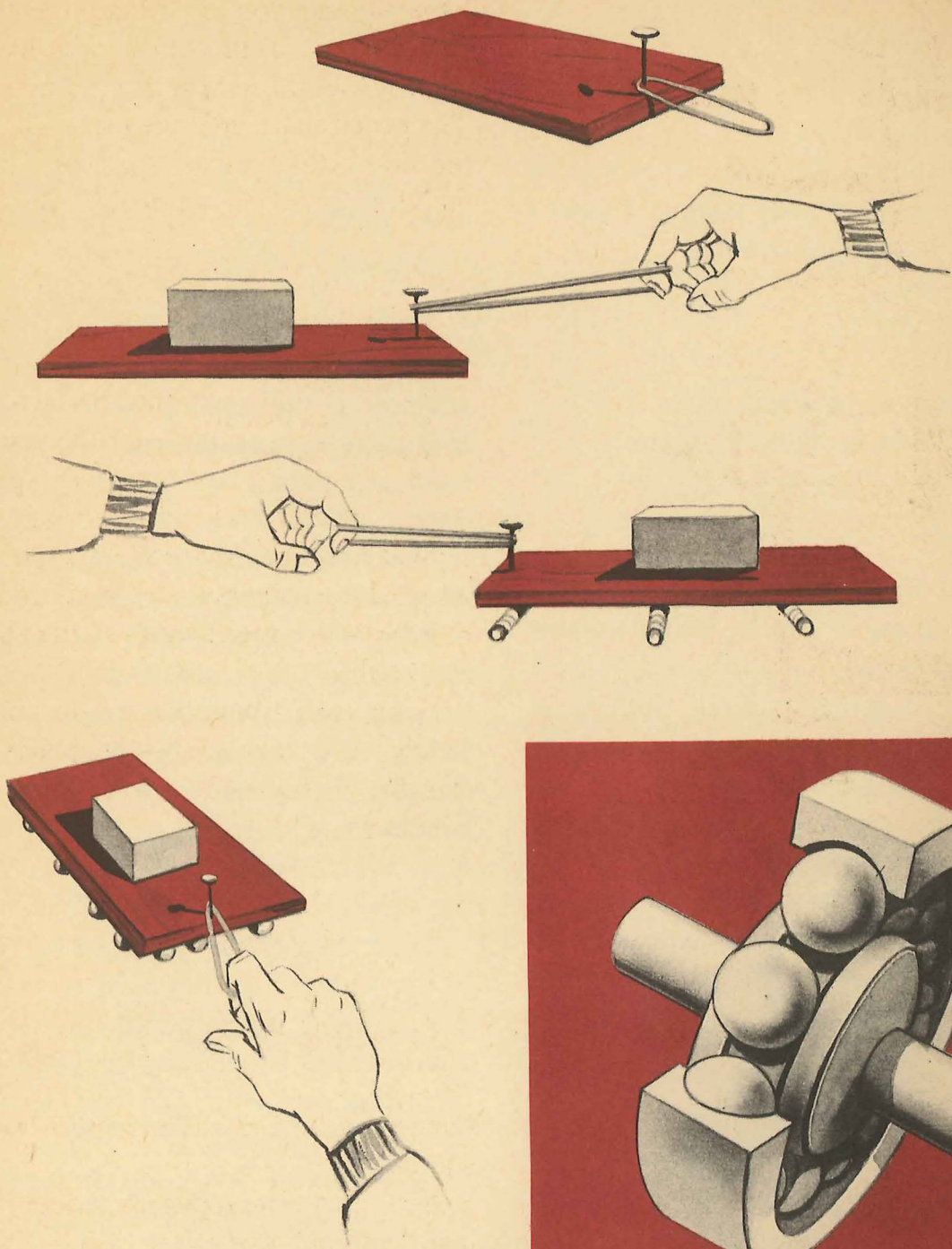
How can you reduce friction?

remember how far the rubber band stretches.

Now put three pencils under the board and pull again. You will find that you need much less force. The rubber band will not stretch as much as the first time.

Now try it again, putting some marbles instead of pencils under the board. The result again will be different.

You have proven that a rolling ob-



Wheels reduce friction so that the rolling object has less friction than the sliding object. On the right is a cutaway view of a wheel and axle showing the ball bearings (hardened steel balls) which are used to reduce friction.

ject has less friction than a sliding object. The difference between the pencils and the marbles is the same as that

between the roller bearings used in heavy machinery and the ball bearings used in the wheels of an automobile.

How to Make a Lift Truck

You will use:

A cigar box

Paper fasteners

Two empty milk cartons (be sure to rinse them thoroughly with cold water)

One pencil with eraser

Scissors

Paper clip

Compass

A knife — or sharp cutter

Small box — about 1" square

Pliers

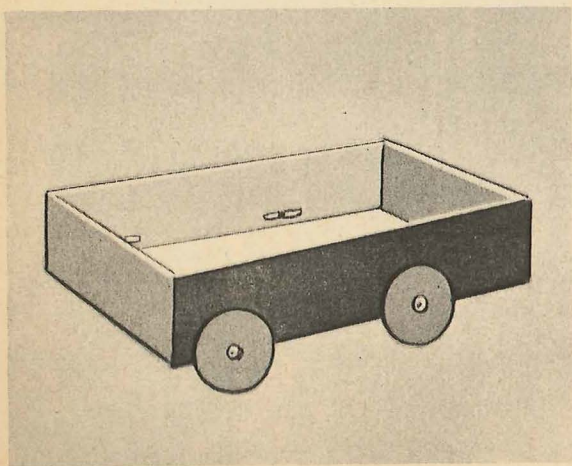
Do this:

With the compass, measure off on a sheet of paper a circle about the size of a half dollar.

Make a complete circle and cut it out. Now you have a model of a wheel.

With the scissors, cut out one side of a milk carton. Using your model as a guide, cut out four wheels.

The paper fasteners will serve as axles. Bore a hole in the center of each wheel. Be sure to twist the paper fastener several times through the hole to make it ride easily.



Since most cigar boxes are made of several thick layers of paper — or very thin wood — you will have no trouble making four holes for the axles. You are now ready to attach the wheels to your truck. Put the fasteners through the holes in the sides of the truck and open up the ends inside the box to secure the axles.

Try to roll it. *Hint:* If the wheels are not very sturdy, double them by making another set and stapling them together. If you are very ambitious, you can try making the truck with a cab and open back.

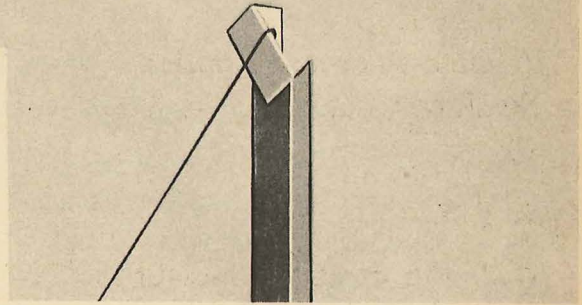
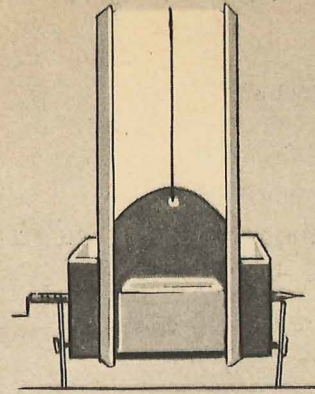
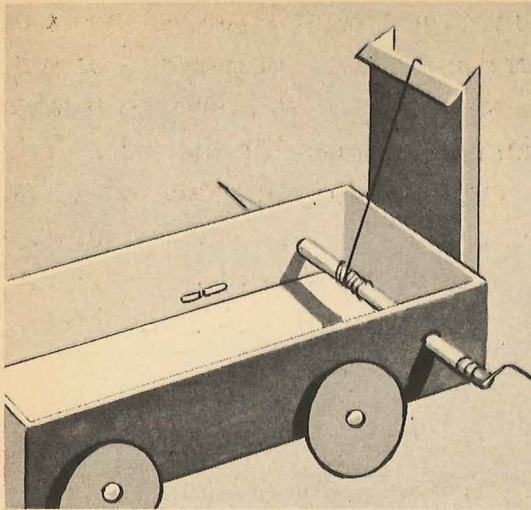
Now you are ready to put the lift wheel and axle into the truck.

Bore two holes through the front of the body of the truck. Put the pencil through them. With the pliers, cut a section of the paper clip. Put one end through the eraser. Now you have a handle for your wheel and axle. *Question:* Which is the wheel and which is the axle?

Tie a piece of strong thread securely to the center of the pencil. If you make a little notch in the pencil, the thread will not slip. By turning the handle of the wheel and axle, you can wind or unwind the thread.

Now you are ready for the track of your lift truck. Cut off one side of a milk carton and bend the two long sides over to face each other.

Cut another piece — the runner — one third the length of the track, but a little narrower to fit into it. Try to see if it fits and rides smoothly. Punch a hole at the top of this runner and tie the end of the thread into it.

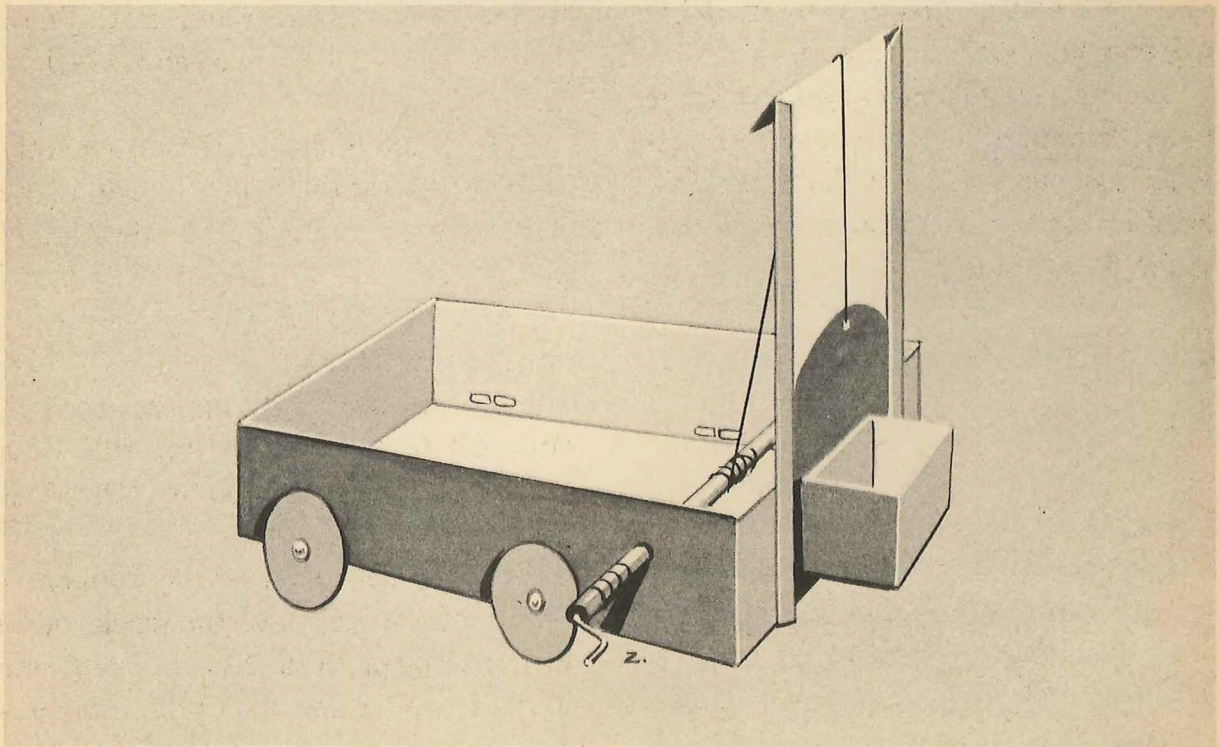


Attach the small box to the runner, either with staples or paper fasteners.

You are now ready to fasten the track and runner and box onto the front of the truck. Your stapler — or paper fastener — will do.

One more hint: Be sure to make a round edge for the thread to glide over the track.

Put some weight in the little box and wind up your wheel and axle. You are now ready to operate a lift truck.



By following the directions, you should be able to construct a lift truck like the one shown in the illustration.

How to Make a Freight Elevator

You will use:

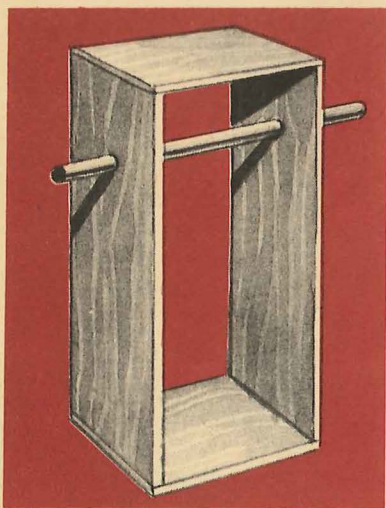
One wooden box
One large dowel stick
Wire hanger
Cord
Small box
Friction tape

Do this:

Remove the cover and base of the box. Make sure that the frame doesn't wobble by reinforcing it with angles. This is going to be a heavy-duty elevator, so it must be sturdy.

Bore two holes about two inches from the top and put the dowel shaft through.

Make a notch in the center of the dowel shaft and tie the cord to it.



Now cut about six inches of the wire. Bend it into shape. It should be as rigid as possible, since it will serve as a handle for your wheel and axle.

Using the friction tape, wind the handle to the axle — many times, in a

crisscross manner. Be sure it is tightly wound. Try it. Does it slip?

Of course, if you have an old handle that you can spare, use it. See if you can be an inventor.

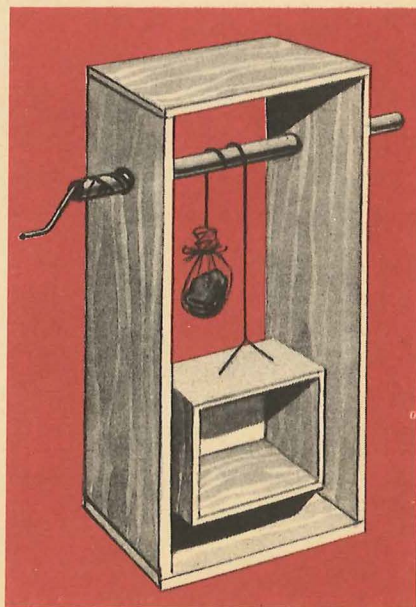
Attach a box to serve as a car for your freight.

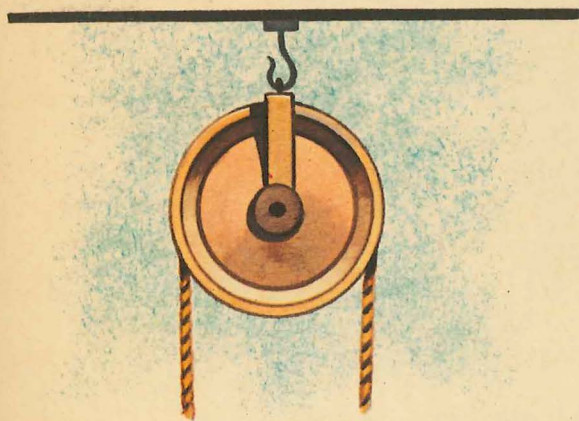
Wind the wheel and axle. Do you hear the dowel shaft squeak when the handle is turned? Why? Do you think a bit of grease or petroleum jelly might eliminate the noise? Try it.

If you want to do still better, try attaching a counterweight. Do this:

Place a stone weighing about half a pound in a small plastic bag and tie it with cord.

Instead of tying your cord to the notched dowel, attach the bag with the weight to the end of the cord and let it serve as the counterweight. As the freight car goes down, the counterweight will go up, and the other way round, too.





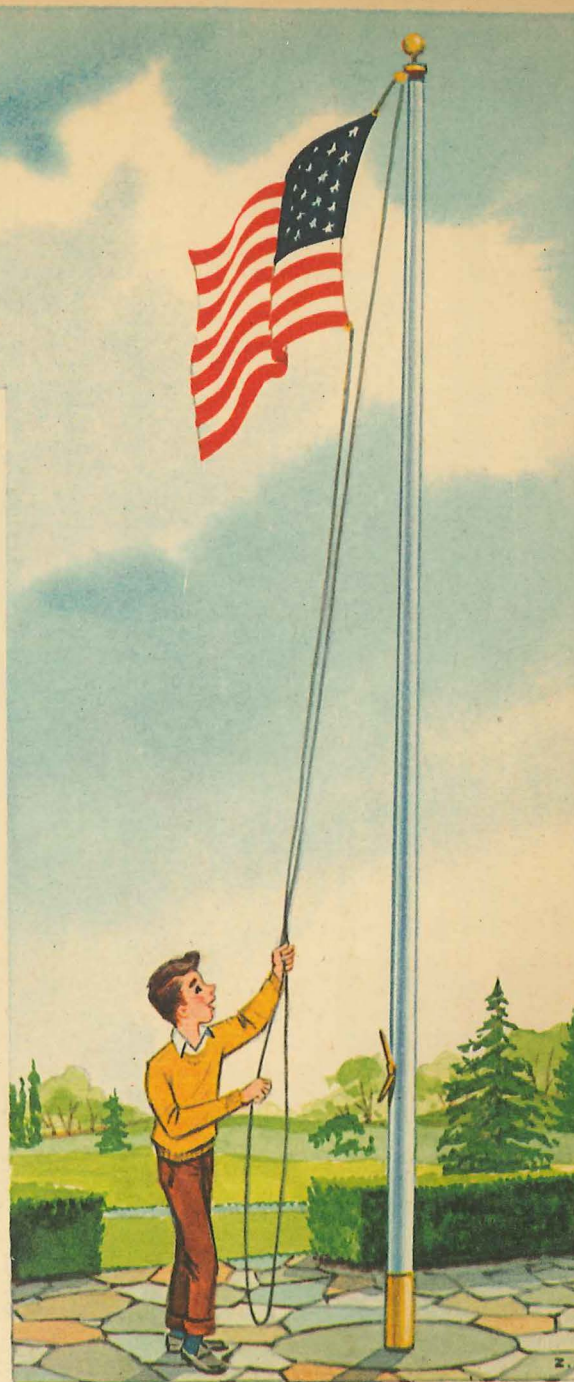
The Pulley

So far, we have made the acquaintance of five of the six basic machines. We have learned that machines, whether compound or basic, do not make less work. They enable man to do work with less effort. They make work easier. We have learned that machines are used for greater speed or for greater force. — whichever suits the user best. A machine cannot give both increased force and increased speed at the same time. We have seen how the lever best illustrates the value of all machines, because every machine, in a sense, gives leverage (or *mechanical advantage*, as the scientists call it).

Now it is time to meet the pulley, a basic machine that works very much like a first- or second-class lever.

Why is the pulley often called a wheel with ropes?

of five of the six basic machines. We have learned that machines, whether compound or basic,



The pulley enables you to raise and lower the flag.

It is a grooved wheel, or combination of wheels, used in combination with a rope or chain to lift heavy weights or, as we shall soon see, to change the direction of a force. We speak of a fixed pulley when the pulley is fastened by means of a hook to some support. A movable pulley is fastened to the weight being lifted.



The simplest type of pulley is the *single fixed pulley*. It sounds simple indeed, but did you ever try to figure out how, without this simple type of machine, you could raise or lower a flag without climbing to the top of the pole, or how the neighbors on the third floor could get the laundry on and off the clothesline?

Since the pulley is fixed — that is, attached to the top of the pole — and only the wheel turns, we do not get any mechanical advantage. We just change the direction of the force. We tie the flag to one end of the rope and pull the other end of the rope down, and — up goes the flag, to the top of the pole!



The mechanical advantage of the movable pulley is easy to see, especially if you think about what the machine is used for

How is the movable pulley used?

and if you remember your lessons from the inclined plane and the lever. The movable pulley and the combinations we still have to learn about are used to lift weights directly upward. We remember from the story of the inclined plane how difficult this is. You arrange your pulley, as *Figure 2* shows you, fastening the rope on the far end and fastening the pulley to the weight to be lifted, and pulling on the other end.

The mechanical advantage of the pulley, like the advantage of all machines, may be obtained by dividing

the resistance by the effort. There is, however, another method of determining the advantage, which applies only to pulleys.

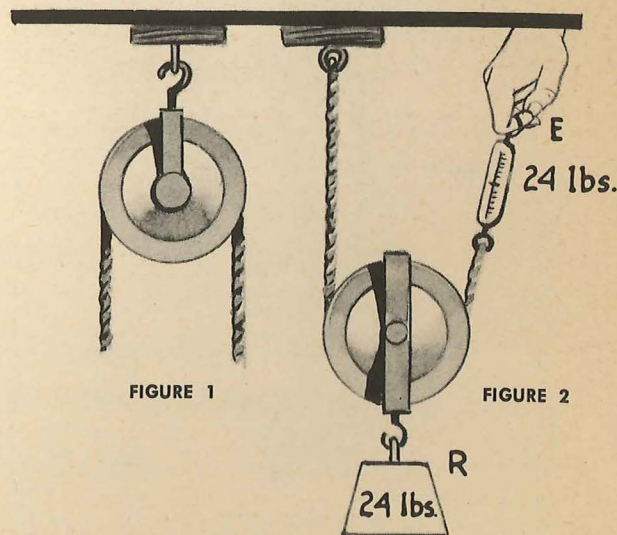


FIGURE 1

FIGURE 2

Single fixed pulley (left) and movable pulley (right)

We were interested with our arithmetic to find the mechanical advantage. But let us not forget that in general, in all our figuring, we can apply the law of the lever: Resistance multiplied by the distance it moves equals effort multiplied by the distance it moves. This means that for the pulley in *Figure 2*, for every foot you raise the weight, you have to pull two feet of rope ($24 \times 1 = 12 \times 2$).

You have seen in *Figure 1* the single fixed pulley and in *Figure 2* the single movable pulley. *Figure 3* shows the combination of a fixed and a movable pulley, and *Figure 4* shows the combination of two fixed and two movable pulleys.

How does the combination of pulleys work?

If you look closely, you will see that in *Figure 1*, the weight is supported by one section of the cord; in *Figure 2*, the weight is supported by two sections; in

Figure 3, it is supported by three sections; and in *Figure 4*, by four sections. Now let's see how we can arrive at a special method of determining the mechanical advantage.

In *Figure 4*, we see on the spring balance that the pull to lift twenty-four pounds of weight is six pounds, so the mechanical advantage is $24 \div 6 = 4$. Now, remembering that the weight is supported by four sections of rope, we can see that each section actually carries only one-fourth of the load, or six pounds, and that — as you see registered on the spring balance — is the force exerted throughout the entire length of the rope. Thus, in the pulley — and only in the pulley — the mechanical advantage is equal to the number of strands of rope which support the weight.

Now that we have figured together the example for this combination of pulleys, try to do it without help for the other three examples.

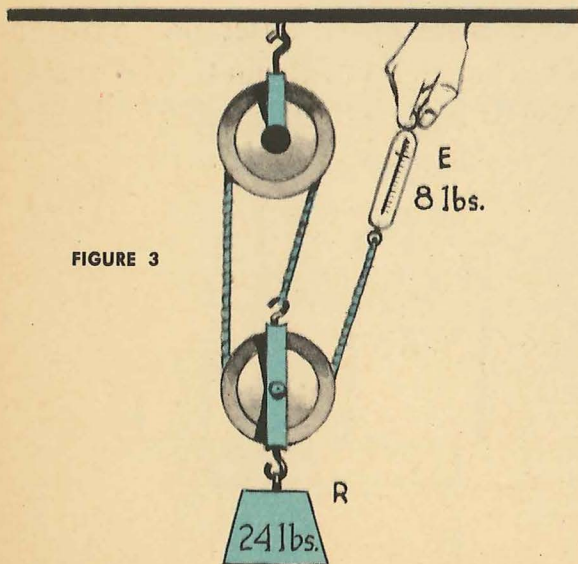


FIGURE 3

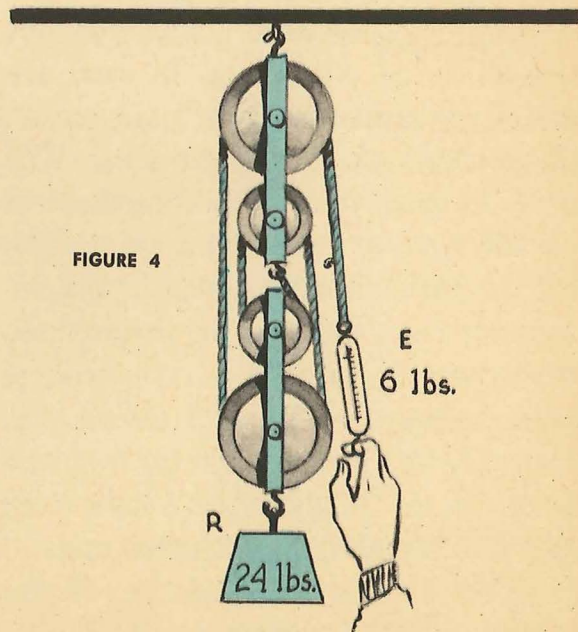
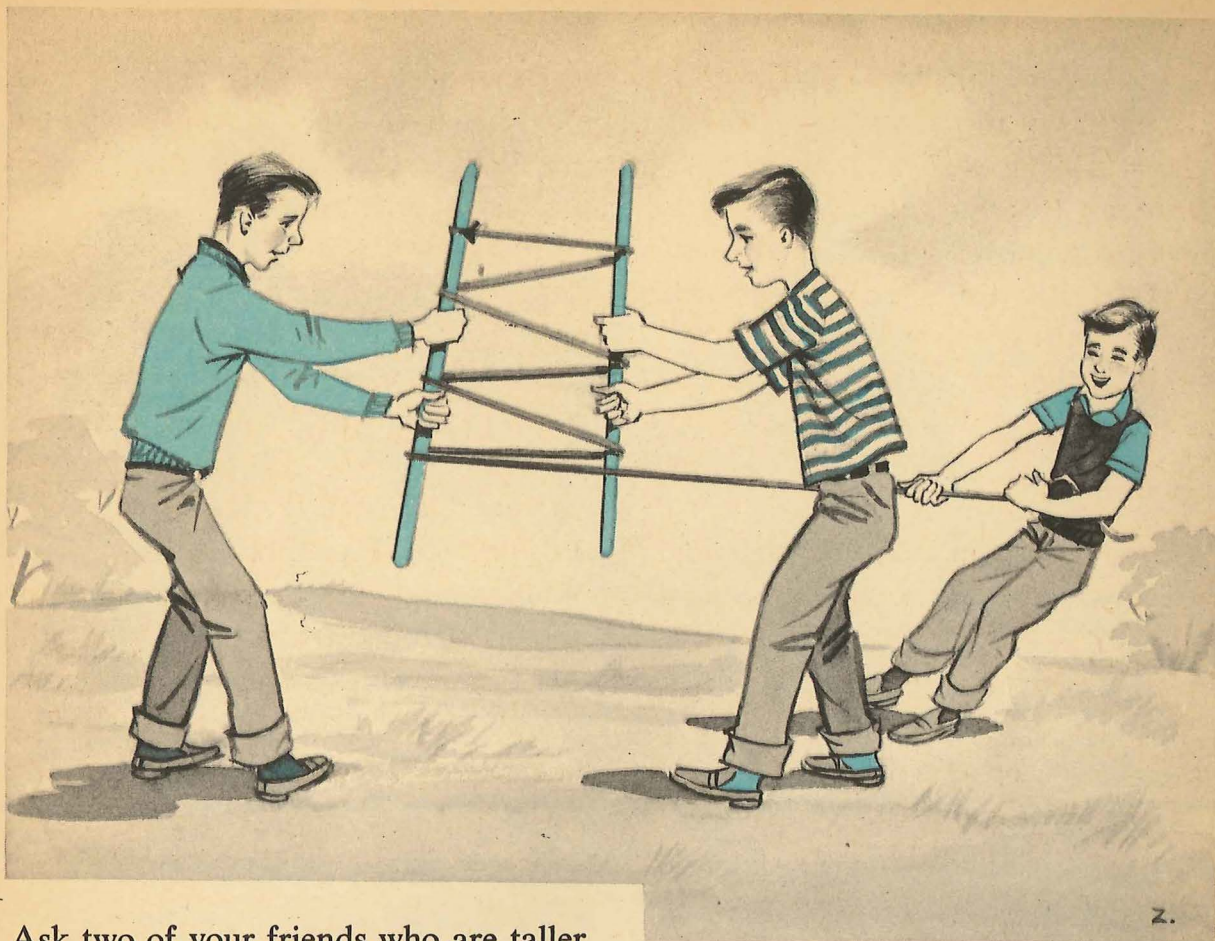


FIGURE 4

Combination of fixed and movable pulleys (left); combination of two fixed and two movable pulleys (right).



Ask two of your friends who are taller and stronger than you to grasp a broomstick each and to stand several feet apart. Tie a clothesline to one of the sticks and wrap it several times around both sticks, as the picture shows. Ask them to hold tight to the sticks while you pull on the rope. You

How strong are you?

With the help of the pulleys, you can be "stronger."

will see that you will pull the two sticks together and they will not be able to keep them apart. After you have accomplished this, explain to your friends how you did it. Here's a hint: you used a combination of pulleys.

How You Can Experiment With Pulleys

You will use:

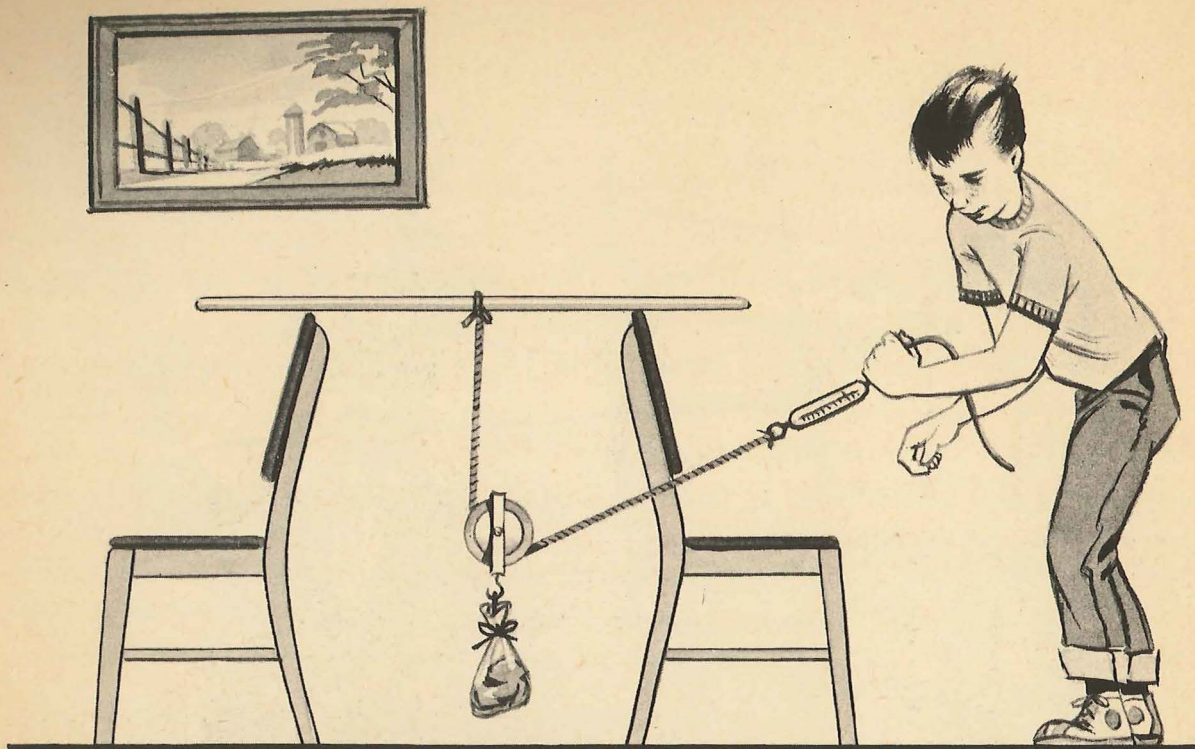
- Pulley, obtained from a five-and-ten-cent store for about 15¢
- About five feet of cord
- Small plastic bag
- Four-pound weight (rock)

Spring scale

Broomstick or mop handle

Do this:

Put two chairs back to back, about three feet apart.



Place the broomstick across the top of the chairs.

Attach one end of the cord to the center of the stick.

Place the cord through the pulley so that the wheel rides freely, as if the cord were a track.

Place the weight in the bag and tie it. Attach the weight to the pulley.

Attach the spring scale to the end of the cord and pull up.

This is your own movable pulley, and now you can check all the information that you have learned about it.

What does the scale read? As you know from the previous chapter, it should read two pounds. But it will read a little more than that because here, too, we have to overcome friction.

In the examples on the previous pages you saw a combination of a single

fixed and a single movable pulley which was combined so that the mechanical advantage was three. If you do not remember it well, go back to *Figure 3* on page 36 for another look.

Now you should make your own combination, but hang it differently.

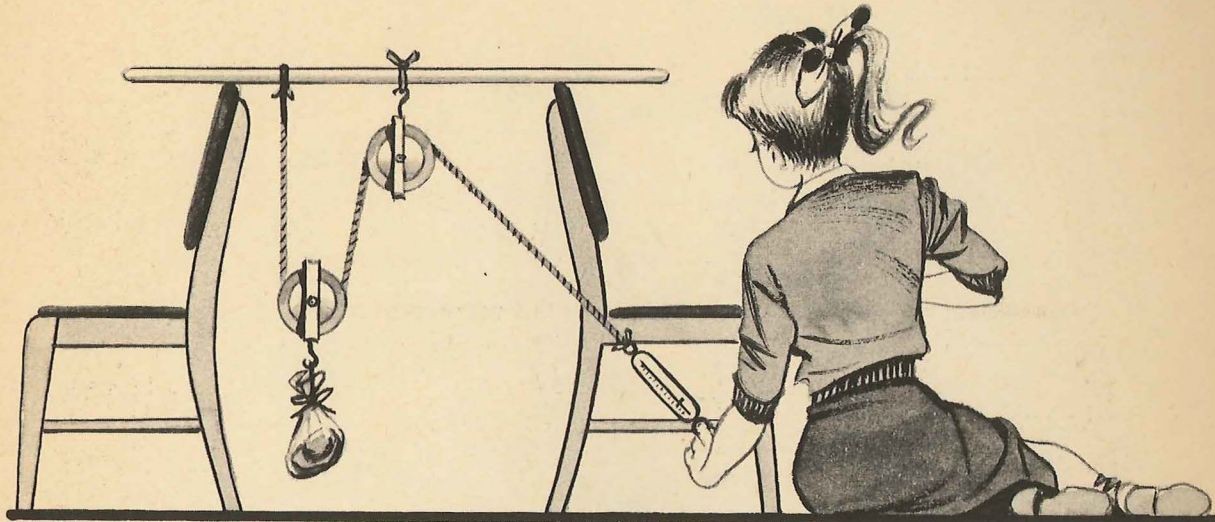
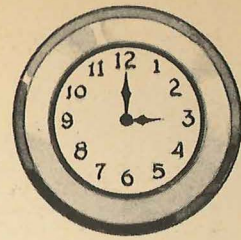
You will use:

- Two pulleys
- A short piece of cord
- About five feet of cord
- Plastic bag
- Four-pound weight
- Spring scale
- Broomstick or mop handle

Do this:

Put two chairs back to back, about three feet apart.

Place the broomstick across the top of the chairs.



Attach one pulley to the center of the broomstick, using a short piece of cord. This will be the fixed pulley.

Tie one end of the five-foot piece of cord to the broomstick.

Pull this cord through the second, or movable, pulley and up through the first, or fixed, pulley.

Attach the free end of the cord to the spring scale.

Attach the weight, tied in the bag, to the movable pulley.

Pull and read the scale. Again it should read two pounds.

You will have to figure out whether the mechanical advantage is the same or different from your first pulley experiment — and whether it is the same or different from *Figure 3*. Whatever your results, you will find that it was easier to lift the weight — easier than in *Figure 3* and easier than in your own

previous experiment — because you were pulling down instead of up.

If you cannot buy pulleys, you can easily make your own. Cut off both wires of a wire clothes hanger at a distance of about seven inches from the hook. Bend the ends at right angles and slip both ends through an empty spool. Adjust the wires to allow the spool to turn freely and then bend the ends down to prevent the wires from spreading.

We have talked all this time about pulling a weight, pulling on the cord, and so forth. You might think, therefore, that the word *pulley* comes from the word “pull.” But it doesn’t. If you learn Greek, you will find that *pulley* comes from the Greek word *polós*, which means “axle.”

Where does the word “pulley” come from?

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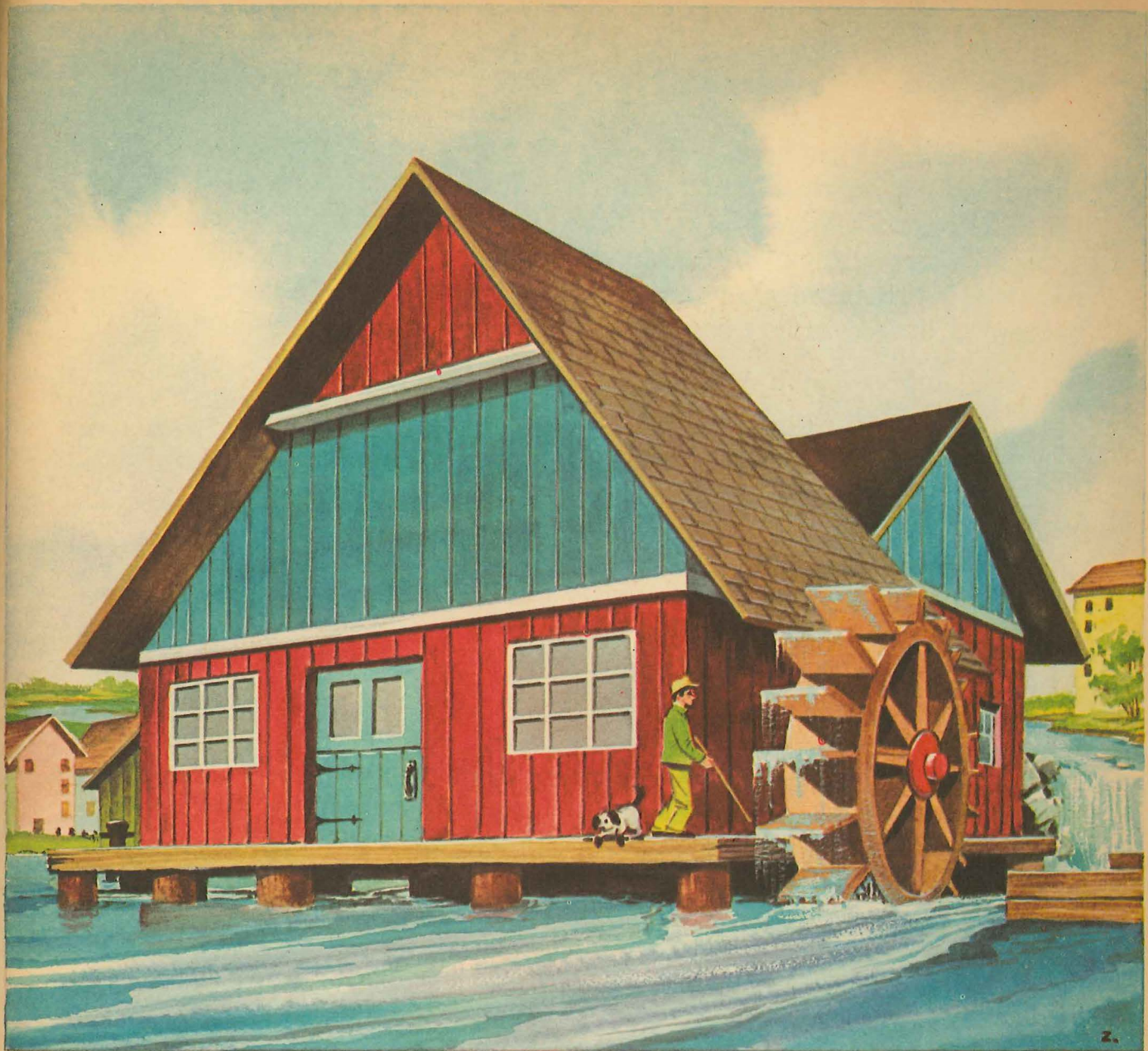


Windmill (above) and water mill (opposite page).

The Sources of Energy

We have learned that in early times man relied entirely on muscular energy. The first step forward came when man learned to supplement his own muscular energy with that of animals. As man came to rely heavily on horse, ass, ox, and camel, he was slow to discover the uses of other natural sources of energy.

In the beginning of the book it was explained that energy is *the ability to do*



work. It was said that there are many forms of energy. Let's look a little more closely into this now, because energy and man's use of it is the main reason for the development of the machine.

If energy is the capacity to do work, then water moving downhill has energy, the air that moves as wind has energy, and — as we know — we “have energy.” What is this energy we have? Can we

What are the different kinds of energy?

make it from nothing? Can we create energy? No. We always have to get it from somewhere. We have to get it from the moving air, the flowing water, or the oxidation of fuel. The oxidation of food provides muscular energy, the oxidation of fuel (when we burn coal or oil) provides energy for the steam engine, and so on.

Matter, as we will learn, may have two different kinds of energy, depending upon whether or not the energy is used or is just there, waiting to be used.

Water going over a waterfall, the weight of the pile driver coming down, steam expanding in an engine, are examples of active energy or, as the scientists call it, *kinetic energy*. The water in a reservoir, the weight of the pile driver resting on top of the machine, are not doing work, but they are in a position to

do work. It is not active energy, but stored-up energy or, in the scientific term, *potential energy*.

Thus, kinetic energy is the energy matter has when it is in motion.

Potential energy is the energy matter has because of its position, its condition, or its chemical state.

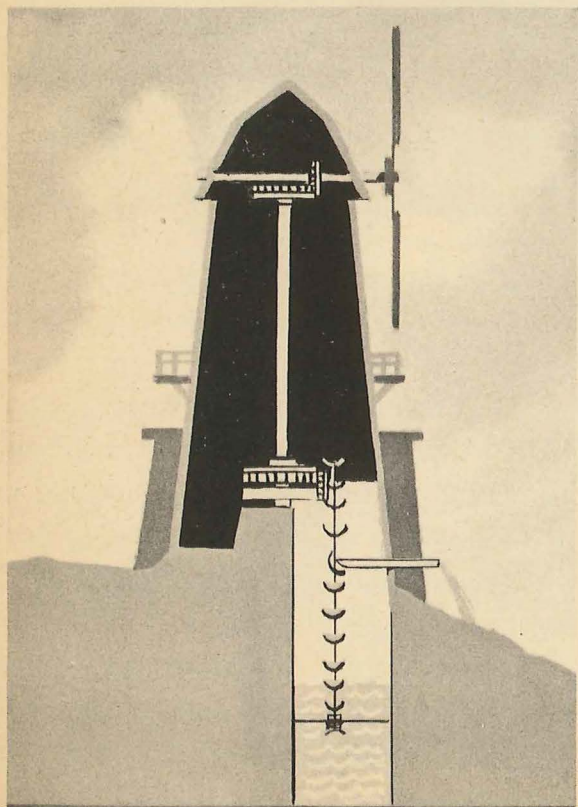
How Man Harnessed the Forces of Nature

(1) *The windmill.* Man learned long ago to use a sail to catch the wind to drive a boat, but it was not longer than a thousand years ago that he attached the sail to a large

How has man harnessed the forces of Nature?

wheel. As the wind blew, the wheel turned. This turned the axle to which the wheel was attached, and by using a combination of cogwheels, grindstones could be put in motion to grind grain into flour.

Later, in the Low Countries of Europe, where large sections of the land are below sea level, windmills were used to pump the water out of the fields. The early windmills had large canvas sails. Today, various improved types of windmills still are in use on farms for pumping water or for generating electricity on a small scale. Modern windmills have metal sails or blades and the wheel is much smaller and lighter. They are constructed in such a way that the wheel can turn freely and always catch the wind, no matter from which direction it blows.



This is a cutaway view of a windmill showing the combination of wheel and axle and cogwheels.

(2) *The water wheel.* While the ancient civilizations of Mesopotamia used crude water wheels to help in the irrigation of the fields, not until the early Middle Ages did the people of Europe develop mills driven by the use of falling water.

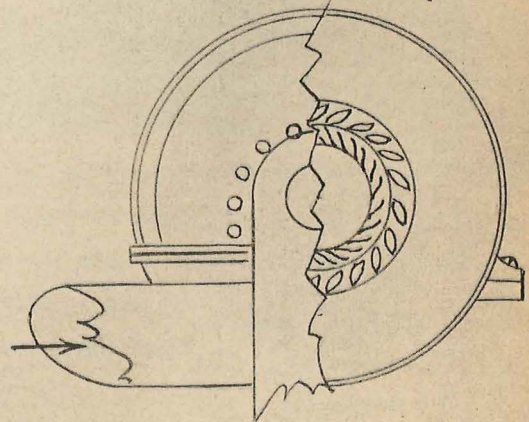
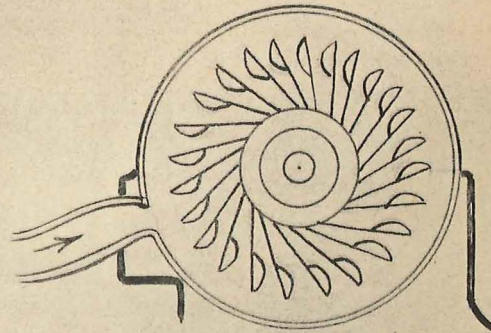
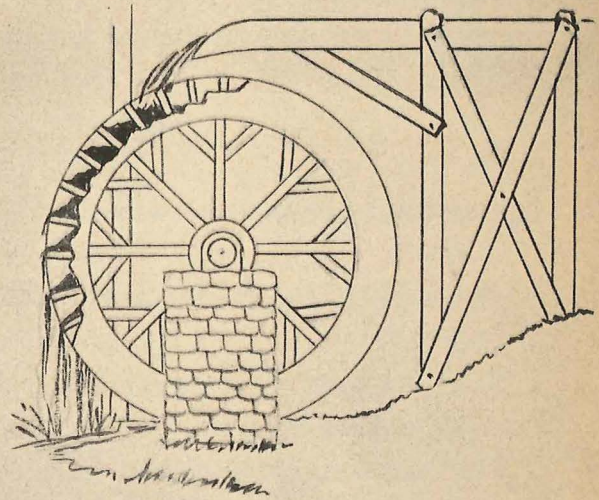
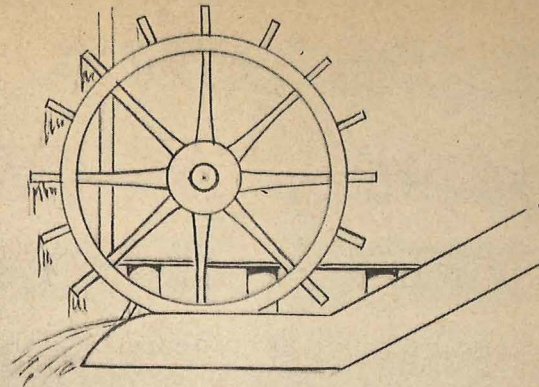
In the course of time, several types of water wheels were developed, two of them closely associated with the early days of the American settlers and early American industry.

The *overshot wheel*, as the illustration shows, is turned by water falling upon the wheel from above.

The *undershot wheel* is operated by the force of running water striking the blades of the wheel from the bottom.

A third kind of water wheel was developed by the engineer Pelton and named for him. The *Pelton wheel* is turned by a strong stream of water directed against its blades from a nozzle. The advantage of the Pelton wheel is that it delivers more power than the overshot or undershot wheel and can be operated at a much greater speed.

The most efficient and useful type of water wheel today is the *turbine*, used to generate electricity. It consists of a large wheel with many blades, enclosed in a case or shell. Water piped from a great height first strikes a set of fixed blades attached to the casing, which causes the water to be directed with even greater force against the blades of the wheel and, in doing so, makes the wheel turn with great speed. While a great amount of energy is lost in overshot, undershot, and Pelton wheels, in the turbine the efficiency is more than 90% because of the casing.



From top to bottom: The undershot wheel, the overshot wheel, the Pelton wheel and the modern turbine.

How You Can Make a Model Water Wheel

You will use:

- A cotton reel or a cork
- 10 pieces of wood or tin
- A meat skewer or knitting needle

Do this:

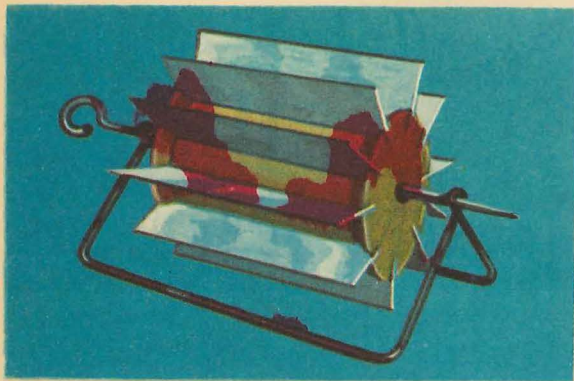
Use the cork or the reel as the hub of the wheel.

Cut slots down the sides, at right angles to the ends, as shown in the illustration. Slide pieces of wood or tin into these slots.

Use the knitting needle or skewer as an axle.

Hang the wheel in a stand made from a metal clothes hanger.

The stream from a tap in your kitchen or bathroom will provide the water power to turn your water wheel.



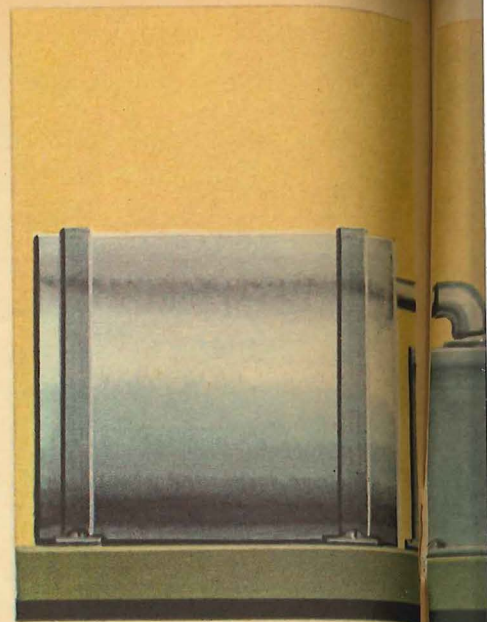
This is your finished model water wheel ready for use.

We have seen now that man has learned to use water and wind as sources of energy to operate machines — more complicated machines than the six basic ones, but still machines that can easily

What are some other sources of energy?

to use water and wind as sources of energy to operate machines — more

Energy can be changed from one form to another. Here, the boiler sets off the steam engine, which activates the dynamo, which lights a lamp, rings a bell and produces a chemical (electrolytic) reaction.

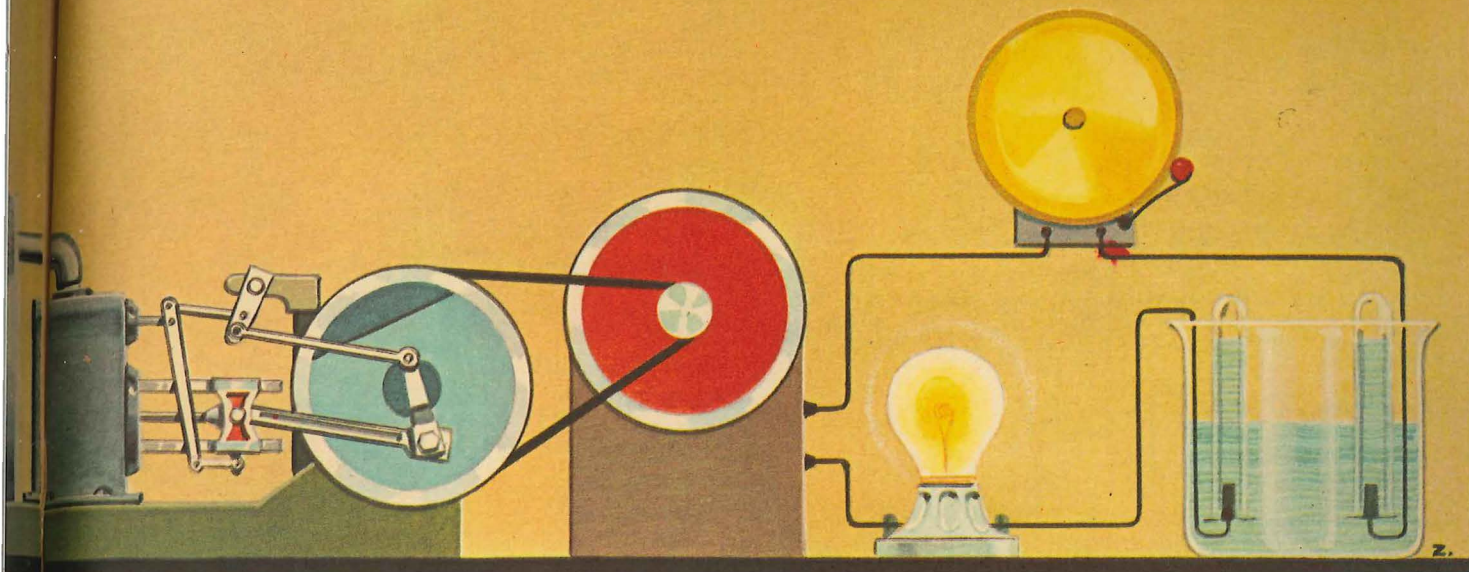


be traced back to the basic machines. However, only a small amount of the world's energy comes from wind and water. Most useful energy comes from fuels such as petroleum, gas, coal and wood. But only in the eighteenth century did man succeed in developing these sources of energy, and only quite recently did he start to develop the most powerful energy of all — atomic energy.

Wood and coal are burned in a furnace to boil water and produce steam that turns a steam turbine or steam engine; fuels that are liquids or gases can be burned in the combustion chambers of gasoline, diesel, or jet engines; and by "splitting the atom," atomic energy is released.

We have shown you and told you about the six basic machines and two early, more complicated machines. We have discussed what makes the machine do work. Let's finish now by explaining the difference between a machine and an engine.

While a machine is any device that



makes work easier by multiplying the force, changing the direction of the force, or increasing the speed with which the work is done, an engine is a device that is used to convert some form

of energy — usually heat — into mechanical energy.

With this definition, we are near the end of our book, and at the beginning of the machine and atomic age.

Some Important Ideas for You to Remember

Machines have changed our ways of living in many ways — in getting food, making clothing, heating and lighting our homes, and our means of having fun. They have made work easier.

If we understand the simple machines, we can go on to understand the compound machines that are so much a part of our lives. These compound machines can be observed in the home, school, hardware store, toy store, factory, farm, garage and office.

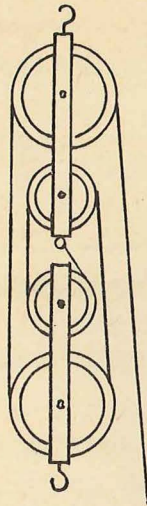
Here are some important ideas about machines for you to remember:

1. If something has to be moved, we have to pull or push it. We use force to bring about movement.

2. We can use more force if we wish to pull or push faster.
3. The force that usually works against us when we push or pull along the ground is friction.
4. When we try to row a boat, we are resisted by the water.
5. Airplanes are resisted by the air through which they fly.
6. This force — resistance — can only be overcome by a greater force pushing against it. If the resistance is greater than the force, then we cannot move our object and no work is done.
7. Work is done only when something is moved.

Some Important Terms for You to Remember

BLOCK AND TACKLE: A combination of fixed and movable pulleys used for hoisting heavy objects.



COMPOUND MACHINE: A machine consisting of two or more simple machines.

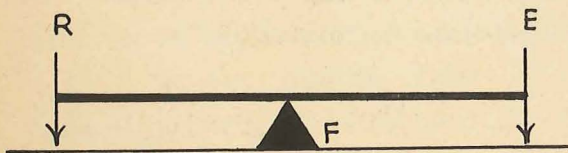
EFFICIENCY: The useful work done by a machine compared with the amount of work put in.

EFFORT: The force exerted on a machine.

ENERGY: The ability to do work.

ENGINE: A machine that changes energy from one form to another, usually mechanical energy.

FIRST-CLASS LEVER: A simple machine where the fulcrum is between the effort and the resistance, as in a seesaw.



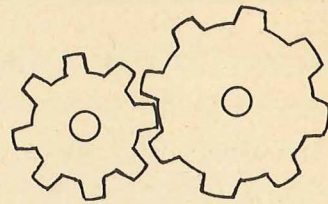
FOOT-POUND: Unit for measuring work done. One foot-pound is work done in lifting a pound one foot.

FORCE: A push or a pull, in order to move something or to stop something from moving.

FRICTION: The resistance that is caused when one object moves against another.

FULCRUM: The pivotal or "resting" point of a lever.

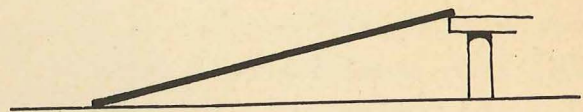
GEARS: Wheels with teeth or cogs that engage other gears.



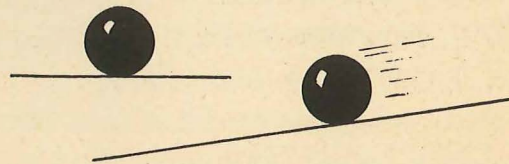
GRAVITY: The force of attraction between the center of the earth and objects on it or above it.

HORSEPOWER: Unit for measuring power—550 foot-pounds per second.

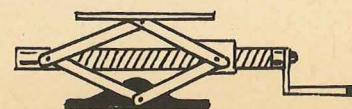
INCLINED PLANE: A simple machine consisting of a leaning surface along which objects may be pushed or pulled.



INERTIA: The tendency of a stationary object to remain at rest and a moving object to keep moving.



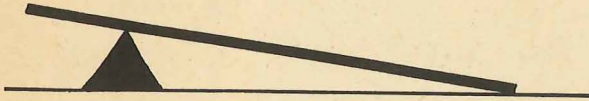
JACK: A machine used for lifting very heavy objects.



KILOWATT: One thousand watts.

KINETIC ENERGY: Energy of an object due to its motion, as a moving car.

LEVER: A simple machine upon which an effort is applied to gain force, speed or distance.



MACHINE: A device used to make work easier.

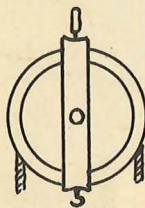
MECHANICAL ADVANTAGE: The gain in force obtained by using a machine.

PITCH: The distance between the threads of a screw.

POTENTIAL ENERGY: Energy of an object due to its position, as a rock at the edge of a cliff.

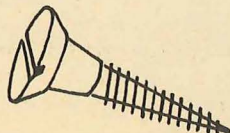
POWER: The rate of doing work, usually measured in watts or in horsepower.

PULLEY: A simple machine consisting of a grooved wheel over which a rope passes.

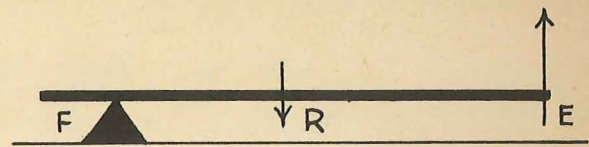


RESISTANCE: The force to be overcome by a machine.

SCREW: A simple machine consisting of an inclined plane wrapped around a cylinder.

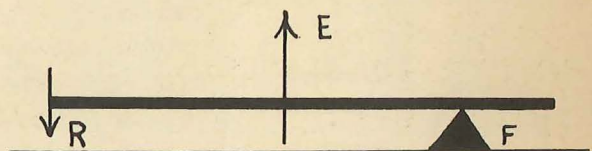


SECOND-CLASS LEVER: A simple machine where the resistance is between the effort and the fulcrum, as in an oar.



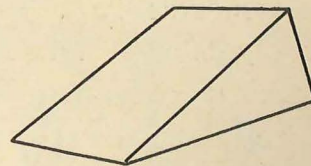
SIMPLE MACHINE: One of the six basic devices used to do work — inclined plane, lever, pulley, screw, wedge, and wheel and axle.

THIRD-CLASS LEVER: A simple machine where the effort is between the resistance and the fulcrum, as in a fishing rod.

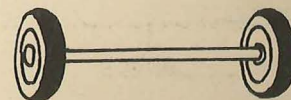


WATT: Unit for measuring electrical power.

WEDGE: A simple machine that is thick at one end and sloping to a thin edge at the other.



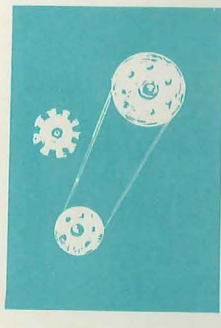
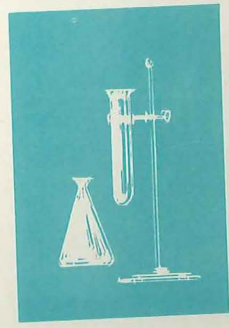
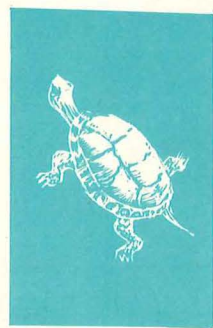
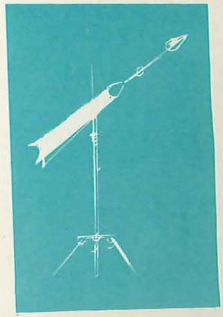
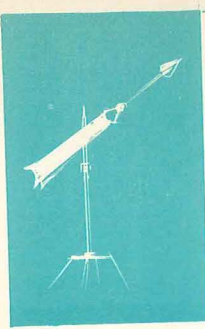
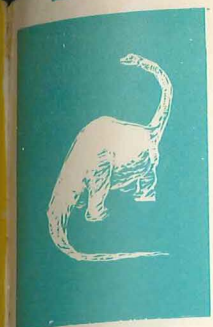
WHEEL AND AXLE: A simple machine consisting of a wheel or crank attached to an axle.

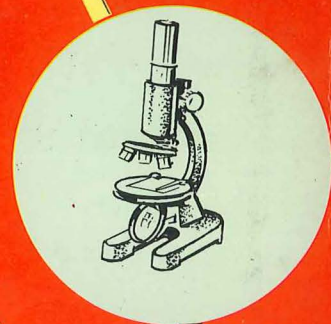


WORK: Applying force to move an object from one place to another.



Even the most complicated modern machines are combinations of two or more of the six basic machines described in this book. The picture above, for example, shows some of these basic machines. How many can you find?





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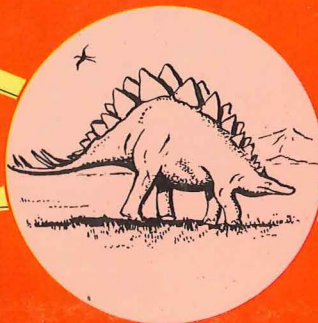
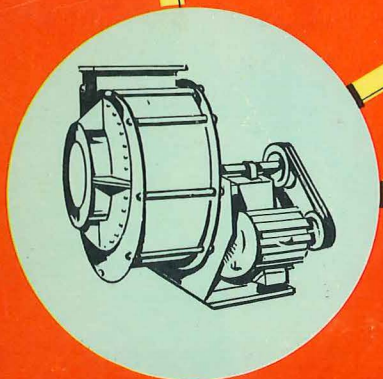
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